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The role of trails and trail-users in the spread of non-native plants

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THE ROLE OF TRAILS AND TRAIL-USERS IN THE SPREAD OF NON-NATIVE PLANTS

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ABSTRACT

THE ROLE OF TRAILS AND TRAIL-USERS IN THE SPREAD OF NON-NATIVE PLANTS

by Anne G. Crealock

As outdoor recreation grows in popularity, the need to balance preservation with recreation becomes more urgent. This study examines the role of trails as habitat for exotics and as vectors for invasion in coastal prairie within preserves managed by the Midpeninsula Regional Open Space District. Part I of this study is a correlational study comparing the effects of hiking and multi-use trails (permitting hikers, mountain bikers, and horses) on invasive species cover. Part II is an experiment in which test plots received one of six treatments: (1) trampling by a hiker; (2) trampling by a mountain bike; (3) trampling by a horse; (4) horse manure; (5) horse manure with disturbance; or (6) no treatment. Results suggest that the germination of several exotic and native species is promoted by some trampling and that any trail, regardless of user group, may impact native and non-native cover.

Key Words: Exotic plants, Trails, Open space management, Coastal prairie

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Introduction to the Research Problem

In recent decades, outdoor recreation has gained popularity (Liddle 1975; Cole 1978; McQuaid-Cook 1978; Cole 1989) leading to more opportunities for building public appreciation and knowledge of nature. However, increased use of parks and preserves can also be associated with the degradation of the very natural resources that are meant to be preserved (Liddle 1975; Cole 1978; Bright 1986).

Trails in protected areas can function as both a source of disturbance and a source of seeds from plants that are not native to the area. Exotic plants, according to Coblentz (1990), are those that are "...not native to an ecosystem, into which they have been introduced as a result of human activity." These seeds may be introduced via fur, clothing, hiking boots, bicycle tires, hooves, and horse manure, among other vectors. The germination of many seeds and the success of some species can be fostered by the consistent source of disturbance provided by trails (Benninger-Truax 1992; D'Antonio, 1993; Zink et al. 1995).

Once established, some non-native plants become invasive, displacing native plants (Bright 1986; Tyser & Worley 1992) and altering the host ecosystem (Coblentz 1990; Mack et al 2000; Williams & West 2000). It is difficult, if not impossible, to predict which plants will be invasive. Therefore the continued introduction of non-native plants elicits great concern. By 1968 alone, estimates of the number of exotic plant species in California ranged from 674 to 975 species (Mooney et al. 1986, 258).

Background

Several challenges face managers of public open space. Managers must seek a balance between providing a pleasant experience for the trail-user and maintaining the integrity of the protected ecosystem. This balance is difficult to maintain. For instance, the construction of a trail often requires the work of a crew with mechanized means of vegetation removal. During the process of trail construction, substantial trampling may also occur in non-target vegetation. When vegetation is removed, the soil is exposed to the sun, wind, and rain, greatly changing the sunlight availability, temperature, and amount of direct precipitation received within this microhabitat (Cole 1978). These changes are compounded by trampling by hikers, mountain bikers, and horses to remove the exposed organic layers of soil. Without the organic layer, fewer nutrients enter the soil, reducing its ability to support flora (Bright 1986; Hammitt and Cole 1998, 6). Trampling also compacts the mineral layers which reduces the amount of water and air that can infiltrate the soil (Bright 1986). Scientists speculate that it may take centuries to reverse such damage (Hammitt and Cole 1998, 11).

The trail corridor is not the only area to be affected by trail-users. Soil that is washed away by rains may enter neighboring aquatic systems, increasing turbidity and degrading habitat quality (Wallin & Harden 1996). Trails also alter biotic communities by affecting plant dispersal, drainage, and animal excretion patterns (Cole 1978). Adjacent vegetation also receives some trampling from users who go off trail, walk abreast, or walk around obstacles, such as perpetually wet areas (Leung and Marion 1999). Trails, then, provide a constant supply of disturbance to the communities through which they run.

These conditions may create habitat favorable to invasive non-native plants, which are often well adapted to disturbance, and reduce habitat suitability for many native species. The competitive edge is often shifted from native plants to invasive exotics.

The invasion of exotic plants into natural communities is considered to be one of the most serious threats to the conservation of native flora and fauna (Coblentz 1990; Zalba et al. 2000). Mack et al. (2000) warn that invasive exotics may create "homogeneous, impoverished ecosystems composed of cosmopolitan species." This is, in part, because some aggressive exotic plants can displace native species (Bright 1986; Tyser & Worley 1992). Coblentz (1990) speculates that invasive organisms may "...cause numerous extinctions in addition to altering the physical environment."

Problem Statement

Recent trends in outdoor recreation are placing added pressure on public open spaces, raising ecological concerns for managers. Currently, more people are visiting public open spaces and, increasingly, they are engaging in activities other than hiking, such as mountain biking and horseback riding. The ecological consequences of these changes are largely unknown.

Some light has been shed upon the subject by several studies that have compared user-types in terms of their capacity to cause erosion and structural damage to vegetation. The results of these studies have shown some consistent trends. First, horses tend to cause more erosion than other trail-users (McQuaid-Cook 1978; Weaver and Dale 1978; Wilson and Seney 1994; Deluca et al. 1998). Second, motorcycles, ridden at speeds below 20 km/h, appear to cause slightly less damage than horses (Weaver and Dale 1978; Wilson and Seney 1994). Third, hikers consistently cause the least amount of erosion (McQuaid-Cook 1978; Weaver and Dale 1978; Wilson and Seney 1994; Deluca et al. 1998) which is approximately equivalent to that of llamas (Deluca et al. 1998). Vegetation cover follows a similar trend. Cover is found to decrease with increasing amounts of disturbance. Vegetation loss is also affected by the type of recreation; hiking affects vegetation the least while mountain bikes and horses affect it the most (Weaver & Dale 1978).

Because different types of trail-use affect erosion and vegetation cover differently within the trail corridor, one may infer that different trail uses may affect species composition differently. Given the ability of non-native plants to establish populations in disturbed areas, it is important to know whether the type of trail-use permitted on trails also affects the extent to which non-native plants invade trail-side vegetation. It is unknown whether multi-use trails (those that include hikers, mountain bikes, and horses) provide habitat for more exotics than hiking trails. Additionally, it is not known how far these trail-side effects extend into adjacent vegetation.

In addition to the disturbance effects, hikers, horses, and bicyclists may aide in the dispersal of exotic plants. For example, there are anecdotal accounts of bicycle tires and horse fur distributing star thistle seeds along trails (Federal Interagency Committee for Management of Noxious & Exotic Weeds 1998; Ken 2001). Similarly, many have speculated whether horse manure is involved in the spread of some non-native plants

(Benninger-Truax 1992), particularly grasses. However, no research has investigated this possibility and whether the manure acts as a dispersal agent, fertilizing agent, or both.

Beginning in 1996, the Midpeninsula Regional Open Space District has been conducting studies in the Coastal Prairie Grassland present in the Russian Ridge Preserve. Various management techniques have been implemented in an attempt to control yellow star thistle (*Centaurea solstitialis*), Harding grass (*Phalaris aquatica*), and other invasive exotic thistles (*Cirsium* spp.). These include controlled burns, hand control, tractor mowing, herbicide, grazing, and planting native seeds. Results showed that some combinations of these techniques have given varying levels of success. However, to further understand these invasions and how to control them, it is necessary to understand the role of trails in degradation of Coastal Prairie Grassland (Kephart 2001).

Research Objectives

This study will investigate the role of different types of trails and recreationists in the spread of non-native plants in two preserves managed by the Midpeninsula Regional Open Space District. Part I of this study will incorporate a survey of exotic plants such as *Centaurea solstitialis* (yellow star thistle) along existing hiking and multi-use trails to determine whether a correlation exists between trail type and exotic plant cover. Part II consists of a germination experiment in which treatments will be applied to off-trail plots.

<u>Part I: Correlational Study of Invasive Herbaceous Flora</u>

1. Determine whether multi-use and hiker-only trails differ in:

a. Cover of exotic plant species adjacent to the trail.

b. Lateral penetration of exotic plant species into adjacent areas.

Part II: Experimental Trampling Studies

1. Determine the effects of three types of trampling on germination of exotic plants:

   a. Trampling by a hiker.

   b. Trampling by a mountain biker.

   c. Trampling by a horse.

2. Determine the effects of horse manure as a seed vector and source of nutrient enrichment on germination of exotic plants.

Hypotheses

Part I: Correlational Study of Invasive Flora

H_{o1}: No difference can be detected in exotic cover directly adjacent to versus several meters away from any trail type.

H_{o2}: Trail-type is not correlated with exotic plant species cover adjacent to trails.

H_{o3}: Trail-type is not correlated with the lateral penetration of exotic species into adjacent vegetation.

Part II: Experimental Trampling Study

H_{o1}: Trampling by a hiker does not affect exotic plant germination.

$H_{o}2$: Trampling by a mountain biker does not affect exotic plant germination.

$H_{o}3$: Trampling by a horse does not affect exotic plant germination.

$H_{o}4$: The application of horse manure does not affect exotic plant germination.

RELATED LITERATURE

Effects of User Group on Soil and Vegetation Structure

Weaver and Dale's 1978 experimental trampling study incorporated hiking, motorcycle riding, and horse-back riding in a *Festuca idahoensis - Poa pratensis* grassland and a *Pinus albicaulis - Vaccinium scoparium* forest. Each path was trampled 1000 times during one summer by one type of trail-user. Measurements were taken before and after trampling each subsequent set of 100 passes. The sign test was used to detect significant differences between treatments ($p < 0.05$). Vegetation measurements showed that on level ground, plant cover was reduced most by horses, followed by motorcycles, and finally hikers. On grassy slopes (15 percent grade), however, motorcycles impacted vegetation cover the most. Researchers observed that trails created by horses in both level and sloping areas were widest, followed by motorcycles, and finally hikers. In general, trails created on slopes experienced more trail width expansion than trails on flat areas. Trail depth increases quickly at low levels of use and then more slowly at higher levels. Trails were generally deeper on slopes than level locations. Horses created the deepest trails, followed by motorcyclists, and lastly hikers. The authors observed greater damage to understory shrubs in the forest than to grasses in the meadows which, they argue, are more resistant to trampling. Upslopes and downslopes were compared in meadows. In general motorcycles caused the most damage on upslopes but the least on downslopes. Hikers and horses removed more vegetation on downslopes than upslopes.

Deluca et al. (1998) examined the effects of horses, llamas, and hikers on soil erosion. Researchers measured sediment yield using a rainfall simulator after several treatments on existing trails: (1) no trampling; (2) 250 passes by a hiker; (3) 1000 passes by a hiker; (4) 250 passes by a llama; (5) 1000 passes by a llama; (6) 250 passes by a horse; and (7) 1000 passes by a horse. These treatments were conducted on prewetted trails and dry trails. ANOVA revealed that user type ($p<0.001$) and number of passes ($p=0.032$) were significant but that wetness of the trail ($p=0.151$) was not. Horses consistently made more sediment available than hikers and llamas. Sediment yields for hikers and llamas were not significantly different from each other but were significantly higher than no treatment.

Wilson and Seney (1994) applied trampling by a hiker, horse, motorcycle, and mountain bike to existing trails to study erosion from a rainfall simulator. Bivariate and multi-variate regression was performed to detect relationships between independent topographic and soil variables, versus water runoff and sediment yield (dependent variables). Soil texture, slope, and user group accounted for 37%, 35%, and 35% of variability respectively. While most results of the user-type comparisons were inconclusive, it is possible to infer that horses created more sediment than other users and treatments on prewetted trails caused more erosion than those on dry trails.

McQuaid-Cook (1978) compiled his anecdotal observations and those of other researchers regarding the impacts of hikers and horses on mountain trails. He concluded that hiking trails lack vegetation because pedestrians compact soil with the flat soles of their boots while equestrian trails lack vegetation because the hooves of horses loosen soil and facilitate erosion. Equestrian trails, then, are more susceptible to gully formation, particularly on slopes, as loosened soil is washed away. On flat areas, however, the author suggests that the damaging effects of hikers surpass that of horses due to various behaviors such as plant collecting and garbage dumping.

Effects of Trail Disturbance on Vegetation Structure and Species Composition

Cole's 1987 trampling experiment compared the effects of three seasons of trampling by a hiker in six different vegetation types in Western Montana, USA. One area was a *Festuca* grassland. The five remaining areas were forested and characterized by the following understory species: (1) the *Symphoricarpos* type - medium sized shrubs and a rhizomatous grass (using subterraneous rhizomes to reproduce vegetatively); (2) the *Clintonia* type - caulescent broad-leafed herbs (having leaves come from several places along the stem rather than only at the base); (3) the *Clintonia-Vaccinium* type - caulescent broad-leafed herbs with short and prostrate shrubs (growing along the ground rather than upright); (4) the*Vaccinium* type (short and prostrate shrubs); (5) the *Xerophyllum* type (short shrubs and a forb with linear, tufted leaves). In each vegetation type, two sets of replicate experimental paths were created. Each set included one control path and sixteen test paths which received different levels of disturbance: 5, 15, 25, 40, 75, 80, 100, 200, 400, 600, 800, 900, 1,000, and 1,600 passes per year. Two test paths received 300 passes, but trampling was spread out over the summer on one of the paths while the other path received all 300 passes at once. (Results showed no consistent differences were detected between the two paths.) In all plant communities vegetation loss increased quickly with increasing passes at low levels, but slowed at higher levels. Graphs of results show an asymptotic relationship between number of passes and loss of vegetation. The *Festuca* grassland exhibited the most resistance to vegetation loss. The *Xerophyllum* community showed a moderate level of resistance; largely due to the presence of mosses. Those communities that experienced high amounts of vegetation loss were typified by short shrubs with brittle stems and tall caulescent forbs. In general, Cole found that as tree canopy cover increases, understory vegetation was more vulnerable to damage. Plants adapted to low light intensities have larger leaf areas and thin cuticles, cell walls, and stems making them, he speculated, more susceptible to damage.

Cole (1978) studied the vulnerability of eight different plant communities to disturbance from trails by sampling vegetation cover and species composition along trails in forests and meadows in the Eagle Cap Wilderness of northeastern Oregon. The communities chosen for study included: (1) *Pseudotsuga menziesii, Physocarpus malvaceous* forests with scattered trees and many tall shrubs; (2) *Pseudotsuga menziesii, Calamagrostis rubescens* savannas with scattered trees and thick grasses; (3) *Picea engelmanii, Thalictrum occidentale* forests with dense trees and forbs; (4) *Pinus contorta, Vaccinium scoparium* forests with open canopy and scattered low shrubs; (5) *Abies lasiocarpa, Vaccinium scoparium* subalpine forests with dense trees and sparse low shrubs; (6) *Pinus alicaulis, Vaccinium scoparium* forests near the timberline; (7) *Stipa occidentalis* grasslands; and (8) subalpine meadows with *Carex* species and forbs. Ten transects in each vegetation type were placed perpendicular to heavily used trails.

Quadrats were then placed directly adjacent to the trail and at a distance of 2 and 10 meters from the trail. Relative frequency and relative cover of each plant species were recorded in each. It was observed that the herbaceous understory vegetation of forests appeared to be more vulnerable to trail impacts than were the plants in meadows. It should be noted, however, that no statistical tests were used to confirm these observations. Cole also noted that the environmental conditions present in areas adjacent to trails favors some plant species, such as Eurasian weeds, over others.

A study by Dale and Weaver (1974) observed that most of the effect of a trail on vegetation is confined to a "surprisingly narrow" corridor in the forests of the Northern Rocky Mountains. Decreasers, those species that occur less often near the trail, were largely unaffected beyond 1 to 2 meters from the trail edge. This category consisted of forest understory species. Increasers, those species that increased toward the trail, were most important only within 1 to 2 meters from the trail edge. This category included native meadow species and weedy species. Increaser-decreasers were those species that increased toward the trail and then decreased directly adjacent to the trail edge. These species were most prominent at 1.2 meters and 2.4 meters from the trail edge. Neutral species were those that showed no change in abundance.

Growth Form and Vegetational Resistance to Trampling Damage

Hall and Kuss (1989) focused upon the morphology of increasers and decreasers in Shenandoah National Park, Virginia in order to explain why some species were better able to resist trampling. Results suggested that those plants with buds located higher above the ground (phanerophytes and chamaephytes) are more affected by trampling than are those plants with buds at or below ground-level (hemicryptophytes and geophytes) (Liddle 1975; Hall and Kuss 1989).

In a similar study, Benninger-Truax et. al (1992) found that understory plants found near trails had different growth forms than those found further from trails. Those species found in greater abundance along trail edges had small leaves near the ground or vegetative reproduction at or below ground-level. Those species found more often in interior plots were shade-resistant forbs typically with large leaf areas and supportive tissue.

Invasion by Non-native Plants and the Role of Disturbance

Biotic invaders can bring about severe damage to native communities and ecosystems. Exotic plants may completely change the fire regime, nutrient cycling, hydrology, and other fundamental ecological characteristics of native systems while decreasing the abundance of native plant species (Coblentz 1990; Mack et al 2000; Williams & West 2000; Vitousek 1986, 166). For example, Kourtev et al. (1998) found significantly higher pH levels and thinner litter and organic horizons in areas of New Jersey hardwood forests that had been invaded by *Berberis thunbergii* and *Microstegium vimineum*. Additionally, salt-cedar (*Tamarix* spp.), which colonizes moist areas such as riparian corridors and marshy areas, accounts for the loss of large amounts of water from their host ecosystems, in some places draining previously surface water (Vitousek 1986, 166). Two invading trees of the Everglades, *Schinus terebinthifolius* and *Melaleuca* *quinquenervia*, have converted wetlands to forest (Ewel 1986, 219; Vitousek 1986, 166). An ice plant in California, *Mesembryanthemum crystallinum*, alters the soil chemistry by bringing salt from deep within the soil to the soil surface, inhibiting the growth of other species of plants (Vivrette and Muller 1977; Vitousek 1986, 168).

Disturbance in a community may refer to changes in the soil surface, soil surface microclimates, resource availability, and other changes to the physical environment (Orians 1986, 136). Disturbance has been shown in numerous studies to contribute to the establishment and/or spread of invasive plants (Baker 1986, 44; Mooney et. al 1986, 262; D'Antonio, 1993). For instance, Jesson et al. (2000) found that the four exotic plants required disturbance for germination but not for subsequent survival. Similarly, soil disturbance was necessary for the invasive succulent *Carpobrotus edulis* to establish in coastal grassland (D'Antonio 1993).

Disturbance may contribute to exotic invasion in several ways. These include: (1) creating new and different microhabitats with conditions favorable for species other than those already present (Orians 1986, 136); (2) by clearing a space of native vegetation, interspecific competition is reduced and exotics may establish (Gross and Werner 1982); and (3) through the redistribution of, or increased availability of, a limited resource (Orians 1986, 136; D'Antonio 1993; Wilson and Tilman 1993) such as sunlight (Hall & Kuss 1989; Brothers & Spingarn 1992). Disturbance, therefore, may shift the competitive advantage to non-native plants, providing a "foothold" from which these plants may further invade a community (Parker et al. 1993).

Exotic species often possess adaptations that allow for the colonization of disturbed areas. For example, many invasive plants have hemicryptophytic or geophytic life forms, thus producing buds at ground level or in the ground. Such traits offer protection from trampling (Liddle 1975; Kuss 1986). Also, several invasive plants, such as Scotch broom (*Cytisus scoparius*) fix nitrogen from the air, enabling them to survive in nutrient-poor areas (Vitousek 1986, 167), such as trail-sides and other areas that lack the organic layers of soil.

The Role of Trails in the Spread of Non-Native Plants

Trails in protected landscapes can be described as corridors of disturbance through relatively undisturbed vegetation. The primary problem resulting from the presence of these trails may be their role in fascilitating exotic plant invasion (Zink et al. 1995).

Tyser and Worley (1992) measured exotic plant species richness along backcountry trails, primary, and secondary roads in grasslands of Glacier National Park, Montana in a 1992 correlational study. At each of nine sites, three 100 m transects were located at 1-2 m (G1), 25 m (G2), and 100 m (G3) from the side of trails and roads. An additional transect directly adjacent to primary and secondary roads (R) was also included at each roadside site. Quadrats measuring 20 cm x 50 cm were placed every 2 m along each transect. Percentage frequency of individual species and mean alien species richness were measured in each quadrat. Tukey multiple comparison tests revealed a consistent pattern along primary and secondary roads. Alien species richness was ordered in the following manner: R > G1 > G2 > G3 ($p < 0.001$). While vehicular transport of alien seeds has likely contributed to these results, past road construction practices likely caused much of the effect. Until approximately 1980, road construction crews revegetated adjacent areas by seeding with alien seed mixes. Backcountry trails showed a slightly different pattern: G1> G2 = G3 ($p = 0.011$). Tyser and Worley had speculated that backcountry trails would be characterized by a low alien species richness due to the lower levels of disturbance and fewer opportunities for alien seed introduction. However, they were surprised to find that alien species were abundant in backcountry areas. The authors speculated that, in addition to the trail and road corridors, other factors, such as fire history and substrate, may have affected the presence of alien plants.

A study performed by Benninger-Truax, Vankat, and Schaefer (1992) explored trails as both habitat and conduits for movement of plant species in Rocky Mountain National Park, Colorado. Two trails in each of the following trail use categories were included: (1) heavy pedestrian and equestrian, (2) moderate pedestrian and equestrian, and (3) light pedestrian and no equestrian. Each trail was divided into 50 equal segments, each containing one sample site. Sites that were not forested were rejected and a second random location was chosen. At each site, locations for three quadrats measuring 0.5 x 1 meter were placed perpendicular to the trail edge: at the trail edge (Edge 1), 1 m (Edge 2), and 5 m (Interior) from the trail.

Results indicated that trail corridors provide habitat for different species than does the forest interior. Fifty-two of the 178 taxa sampled only occurred at one of the plot positions: 30 were only found in Edge 1 plots, 12 only in Edge 2, and 10 only in the Interior. All seven exotic species sampled occurred in one or both edge plots and three were not present in Interior plots at all. Two-way ANOVA tests showed a significant difference in exotic species richness among quadrat locations (F-value = 8.43; $p < 0.001$) but no significant difference in exotic plot cover (F-value 1.27; $p = 0.2888$). Six of the seven significantly abundant exotic species were restricted to trails with heavy and/or moderate equestrian/pedestrian use and were not found along lightly used hiking trails. Surprisingly, however, no significant difference was found in alien species richness among trails of differing uses (F-value = 2.31; $p = 0.1092$). Thus, while alien species richness did not change, alien species composition did change with trail use.

Overall (native and non-native) species richness, however, was found to significantly differ among different trail use types (F-value = 5.31; $p = 0.0051$). Twenty-five taxa showed significant differences in their number of occurrences among trail use categories, but none showed an effect on their percent cover. Moderately used trails gave the highest richness, plot cover, and average species cover overall. Analysis indicated that overall species richness was higher on moderately used trails than it was on lightly used trails, but richness did not differ significantly between moderate and heavily used trails.

In order to study the trail corridor as a "conduit for species movement," Benninger-Truax et al. measured distances from trailheads and trail intersections, or nodes. Distance from trailheads was found to have a significant negative correlation with overall plant species richness but not with exotic species richness.

An additional source of non-native seeds has been speculated by Dale and Weaver (1974) and Benninger-Truax et. al (1992); horse manure dropped along equestrian trails may function as one seed source for some exotic plants.

Summary

Many of the studies that investigated the differences between trail-user type did so in terms of erosion. Most of these studies concluded that hikers generally cause the least erosion of all recreationists. While horses often created the highest amounts of erosion, motorcycles rivaled horses in some studies. Similar trends were seen when measuring loss of vegetation cover.

In general, studies suggest that trail corridors serve as habitat for species often categorized as increasers, or species that favor disturbance. These species often include exotics. Many of these exotic species display growth forms which help to resist damage due to trampling. Several of these plant species are capable of invading a community, outcompeting native species, and even altering their physical environment.

Two studies have pioneered the study of exotics and trails. One study, by Tysor and Worley (1992), generally found a gradient of decreasing alien species richness away from trails. These researchers were surprised to find a high alien species richness even on backcountry trails. This finding led them to speculate that other forces had influenced their abundance. The other study, by Benninger-Truax, Vankat, and Schaefer (1992) studied heavily used pedestrian/equestrian, moderately used pedestrian/equestrian, and lightly used pedestrian trails. Moderately and heavily used hiker and horse trails differed significantly in exotic species richness from lightly used hiking trails. It is unclear, however, whether this difference was due to the increased amount of use or the differing type of use.

METHODS

Study Sites

In 1972, taxpayers voted to create a public agency referred to as the Midpeninsula Regional Open Space District to serve northwestern Santa Clara County, in the South San Francisco Bay Area, California. Four years later the voters expanded the District into southern San Mateo County. Its mission is:

> "To acquire and preserve a regional greenbelt of open space land in perpetuity; protect and restore the integrity of the natural environment; and provide opportunities for public enjoyment and education, consistent with ecological values."

The district is funded by several sources. District property taxes, at the rate of 1.7¢ per $100 of assessed property value, provided $10 million of the 1996-1997 fiscal year budget. Federal and state grants, donations, as well as interest and rental income also contribute to the revenue.

Over 18,600 hectares (46,000 acres) of land have been preserved in the South and West Bay Area as of the summer of 2001 (Craig Britton, 2001). Several of these preserves are situated together off Skyline Boulevard in the Santa Cruz Mountains west of Silicon Valley (Figure 1). This region is referred to as the Skyline Region. The Open Space Preserves encompassed in this region include: Rancho San Antonio, Purisima Creek Redwoods, El Corte de Madera, Windy Hill, Los Trancos, Long Ridge, Rancho San Antonio, Monte Bello, and Skyline Ridge Open Space Preserves (Midpeninsula Regional Open Space District 2000a).

Skyline Ridge Open Space Preserve

Skyline Ridge includes 672 hectares (1,661 acres) of chaparral, grassland, riparian habitat, mixed evergreen, and oak woodland. Two bodies of water are also present: Alpine Pond and Horse Shoe Lake. Sixteen kilometers (10 miles) of trails are open to the public. The David C. Daniels Nature Center is seasonally open to the public for educational purposes (Midpeninsula Regional Open Space District 2000a).

Monte Bello Open Space Preserve

During the late 1800s and early 1900s, this area was dominated by several dairy ranches: Black Mountain Ranch, Stevens Creek Road Ranch, and Monte Bello Ranch. Currently touted as one of the richest Midpeninsula preserves in wildlife and ecosystem diversity, this 1,126-hectare (2,782-acre) area encompasses rolling grasslands, dense riparian forests, the upper Stevens Creek watershed, and 24 kilometers (15 miles) of trails. Canyon trail takes hikers and mountain bikers along part of the San Andreas fault as well as Stevens Creek among California Bay trees (*Umbellularia californica*), Douglas firs (*Pseudotsuga menziesii*), herbs, and ferns. Black Mountain (el. 2800') marks the tallest point in the South Skyline Region. Wildlife sightings include black-tailed deer (*Odocoileus hemionus*), bobcats (*Felis rufus*), mountain lions (*Felis concolor*), rodents, red-tailed hawks (*Buteo jamaicensis*), and turkey vultures (*Cathartes aura*) (Midpeninsula Regional Open Space District 2000a).

Study Design

<u>Correlational Study</u>

Four hiking and four multi-use trails were chosen in Skyline and Monte Bello Open Space Preserves for comparison (Figures 2 - 11). Trails were chosen based on whether at least 20 meters of the trail conformed to the following criteria: 1) similar aspect; 2) similar in age; 3) slopes of adjacent hillsides are roughly similar; 4) segments are located within areas of coastal prairie; 5) members of each pair (one hiking trail and one multi-use trail) will be located in relatively close proximity to one another; 6) the pairs of trail segments will be geographically interspersed.

For each trail segment, three odd numbers ranging from 1 to 19 were randomly generated. These numbers determined the location of each set of 2-meter transects. The side of the trail to be sampled was also determined randomly for each set of transects. However if an obstacle, such as a cliff or change of habitat type, prevented data collection on one of the sides, the other side of the trail was be used. At each of the three locations, five 2-meter transects were placed parallel to the trail at 1, 2, 4, 8, and 16 meters from the trail edge.

<u>Experimental Study</u>

Because no District trails are designated only for mountain biking or horseback riding, it was necessary to conduct an experiment in order to separate the effects of each user group. Six replicates of six treatment plots were created in coastal prairie of Monte Bello Open Space Preserve during the fall of 2001 (Figure 12). Each plot was 3 meters in length and 0.5 meters in width. Plots were located 3 meters apart and were randomly assigned one of the following treatments: (1) no treatment; (2) 40 passes by a hiker; (3) 40 passes by a mountain biker; (4) 40 passes by a horse and rider; (5) untreated horse manure; or (6) untreated horse manure with human trampling disturbance.

Data Collection

Correlational Study

A 2-meter transect divided into 40 segments of 5 centimeters each was placed at each location. Along each transect, all plants overlapping the transect line were counted. For each species, cover was quantified as the length of the transect line (or number of 5-centimeter segments) overlapped by each plant species. Every 5-centimeter section of line a species overlapped translates to 2.5% cover. Percent cover, therefore, was calculated as a percent of the total length of the transect. Total percent cover for all species often exceeded 100 percent. Plants were identified to the level possible at that time of year. See data sheet in Appendix A.

Experimental Study

Plots were examined during the spring of 2002. A 3 x 0.5 meter belt transect was constructed out of PVC piping and divided into 100 equal sections using wire. This quadrat was positioned at each of the 36 trampling plots. Cover estimates were obtained by counting the number of squares (out of 100) in which each species occurred.

Data Analysis

Correlational Study

Two-way analysis of variance (ANOVA) was used to detect differences in exotic cover among distances from trails (1, 2, 4, 8, and 16 meters) and trail types (hiking and multi-use).

Experimental Study

Data obtained from each trampling experiment will be analyzed using 1-way analysis of variance (ANOVA). Statistical tests were used to detect significant differences between treatments in (1) overall exotic plant cover; (2) cover of several individual species including *Centaurea solstitialis* (yellow star thistle); and (3) species richness.

In addition, species richness and evenness were assessed for exotic and native species using the Shannon Index of Species Diversity (H'):

$$H' = -\sum_{i=1}^{k} p_i \log p_i$$

RESULTS

Correlational Study

Non-native species observed along hiking and multi-use trails include *Centaurea solstitialis* (yellow star thistle) (Figure 13), *Erodium botrys* (broadleaf filaree), *Vicia sativa sativa* and *V. sativa nigra* (spring vetch and narrowleaf vetch), *Medicago lupulina* (black medick), *Anagallis arvensis* (scarlet pimpernel) *Linum bienne* (narrowleaf flax) and *Rumex acetosella* (sheep-sorrel), *Sonchus* species (sowthistle), *Crepis* spp. (hawk's-beard), and *Carduus pycnocephalus* (Italian thistle). Native species included *Amsinckia* spp. (fiddleneck), *Trichostema lanceolatum* (vinegar weed), *lupinus* spp. (lupine), and *Eremocarpus setigerus* (turkey-mullein). Cover of all species was highly variable.

Proximity to Trails

Data collected during the fall of 2001 suggest that native plant cover decreases with proximity to the trail edge. Cover of total mean percent cover of native species tended to increase further away from the trail. Native cover at 2 meters and 16 meters was significantly higher than at 1 meter from the trail ($p = 0.028$ and $p = 0.007$, respectively) (See Figure 14).

Distance from the trail edge also varied negatively with *C. pycnocephalus* (Italian thistle) cover. Cover at 2 meters was significantly higher than was cover at 8 meters ($p = 0.047$), and tended to exceed cover at 4 meters ($p = 0.078$) and 1 meter as well ($p = 0.097$) (See Figure 15).

Trail type

Cover by several species and groups of species varied with different trail types. Total exotic plant cover ($p = 0.024$) and *C. pycnocephalus* ($p = 0.012$) were significantly higher along hiking trails. An unidentified non-native *Aster* (either *Crepis* or *Sonchus* genus) also tended to be higher along hiking trails ($p = 0.052$). However, total exotic plant cover did not differ significantly between hiking and multi-use trails if this Aster was excluded from total exotic plant cover ($p = 0.155$) (Figure 16). *Vicia* species (0.065) and *Medicago lupulina* ($p = 0.077$) tended to be more prevalent along multi-use trails than hiking trails. Non-native grass cover was significantly higher along multi-use trails than hiking trails ($p = 0.000$) (See Figure 17).

Trail pair (block) had significantly different cover for most species analyzed. *C. solstitialis* was more dominant in pair 2 than in pairs 1, 3, or 4 ($p = 0.000$), and was less dominant in pair 1 than in pair 2 ($p = 0.000$) and 3 ($p = 0.000$) (Figure 18). Total exotic cover was greater in pair 2 and 4 than 1 and 3 ($p = 0.000$) (Figure 19); the unidentified *Aster* (*Sonchus/Crepis*) was greatest in pair 4 ($p = 0.000$) (Figure 20); total exotic cover excluding the unidentified *Aster was* significantly higher in pair 2 than any other ($p = 0.000$) (Figure 21); *Lupinus* was present in pair 1 and 2 but not in pair 3 or 4; *Vicia* was present in pair 4 but not in other trail pairs; grasses were greatest in pair 3 ($p = 0.000$) (Figure 22), greater in pair 1 than 2 ($p = 0.000$), and greater in pair 4 than pair 2 ($p = 0.018$); total native cover was greatest in pair 1 ($p = 0.000$) (Figure 23); *Madia* was greatest in pair 3 (p = 0.000) (Figure 24); and gopher mounds were most common in pair 4 (p = 0.000) (Figure 25).

Experimental Study

Upon application of trampling by a horse, mountain biker, and hiker, the immediate physical impacts were visually apparent. Visual observations suggested that forty passes by a horse was the most physically damaging to vegetation and soils, followed in decreasing order by forty passes by a mountain biker and finally by forty passes by a hiker. Horse trampling resulted in the most physical damage to vegetation and the most exposed soil (See Figures 26-28).

Plant Community Response

In the spring after the treatments were applied, several non-native forbs were abundant throughout the study area. These included *Centaurea solstitialis* (yellow star thistle), *Erodium botrys* (broadleaf filaree), *Geranium dissectum* (cutleaf geranium), *Plantago lanceolata* (English plantain), *Vicia sativa sativa* and *V. sativa nigra* (spring vetch and narrowleaf vetch), *Sherardia arvensis* (field madder) *Medicago lupulina* (black medick), *Anagallis arvensis* (scarlet pimpernel) *Linum bienne* (narrowleaf flax) and *Rumex acetosella* (sheep-sorrel). Cover of all species was highly variable.

Native forbs included *Sisyrinchium bellum* (blue-eyed grass), *Madia sativa* and *M. gracilis* (coast madia and slender madia), *Lotus* species, *Trifolium* species (clover), *Lupinus* species (lupine), *Sanicula* species, *Juncus* species (rush), *Calystegia* species (morning glory), and *Wyethis* species (mule-ear). Only *Madia* was abundant enough across sites to analyze separately.

Results by Trampling Type

Unlike the correlational study, my experiments showed that user groups affected plant cover differently depending on the species. For several species, both non-native and native cover increased in the following order: control < hiker < mountain biker / horse. Species ranked in this way included the following exotics: *Anagallis arvensis, Linum bienne*, and *Medicago lupulina*; and natives: *Lotus purshianus*, *Madia gracilis* and *M. sativa*, and total native species cover. Overall, cover was lowest in control plots for 7 of the 11 species analyzed individually (including both exotics and natives). Cover was highest in either mountain biker or horse plots for 7 of these 11 species as well.

Non-native species

Cover by several non-native species was significantly increased by each kind of trampling.

Horses. *Anagallis arvensis* cover was significantly higher in plots trampled by horses than it was in control plots (p = 0.026) (See Figure 29). Cover of *Medicago lupulina* tended to be higher in horse plots than control plots (p = 0.087) (See Figure 30). Cover of *Linum bienne* was significantly higher in horse plots than control (p = 0.008) and tended to be higher in plots treated with disturbance along with manure than in plots that only received manure (p = 0.052) (See Figures 33 and 34). In contrast, however, cover was lowest for *Centaurea solstitialis*, *Geranium*, and *Vicia* in plots trampled by horses. Overall, plots trampled by horses contained the highest cover for 3 of the 8 most common exotic species, but they also contained the lowest cover for another 3 of the 8 most common exotic species.

Mountain bike. Total exotic plant cover tended to be higher in mountain bike plots than control plots (p = 0.069). In fact, mountain biking plots had the most cover for 4 of the 8 exotics. Cover for *Centaurea solstitialis*, *Geranium*, and *Vicia*, the same non-native plants that decreased in response to horses, was fairly high in plots that received trampling from hikers and mountain bikers, as compared to control plots (Figure 35).

Hikers. *Sherardia arvensis* was significantly more dominant in hiker plots than it was in control plots (p = 0.034) (see Figure *). *C. solstitialis* cover was significantly higher in hiker plots than horse plots (p = 0.035) and tended to be higher in hiker plots than control plots (p = 0.074) (see Figure *). Hiking plots had the most cover for only 1 of 8 most common exotic species.

Controls. Control plots contained the least cover for 5 of the 8 exotics analyzed individually.

Native species

Although many native species were not abundant enough to analyze individually, surprisingly, total native cover and *Madia* cover were both higher in horse plots than they were in control plots ($p = 0.034$ and $p = 0.037$, respectively) (See Figure? 4).

Diversity

Shannon's index of diversity (H') was calculated for native and non-native species cover with each trampling type. See Table 1 for index values and standard errors. Diversity in all cases was relatively low, suggesting that some species were more dominant than others. Native species diversity was low and did not differ between treatments. Overall plant community diversity was, however, significantly higher in hiker plots than horse plots ($p = 0.025$).

Manure study

Plots that received manure and no disturbance did not differ significantly from control plots. Plots that received a combination of manure and disturbance tended to have slightly higher cover of native and non-native species than plots with only manure, although results were not significant. The exotic *Linum bienne* showed a strong tendency to be more prevalent in plots that received a combination of manure with disturbance than it was in those that received only manure ($p = 0.052$).

Summary

In sum, disturbance associated with short-term recreational trampling affected different species differently, but most non-native species were more dominant when exposed to some level of disturbance. Some species, such as *C. solstitialis*, were more prevalent with low levels of disturbance and others, such as *L. bienne* and *A. arvensis*, were more prevalent with more intense disturbance. However, it is important to note that while total non-native cover increased with trampling, so did total native cover.

DISCUSSION

Correlational Study

<u>Proximity to trails</u>

The fact that total native plant cover tended to decline with proximity to trails, suggests that the construction of trails in general may lead to a decline in local native plant cover. There are several potential explanations for this effect. First, the native species detected in these surveys may have growth forms that are more vulnerable to trampling. Rosettes and tufted growth forms, for example, are well adapted to trampling. However, erect and branching life forms are generally more vulnerable to damage from trampling, particularly those with thin, brittle stems and softer leaves (Kuss 1986). Second, trails could function as vectors for aggressive, non-native species that are able to out-compete native species, as predicted by the literature (Bright 1986; Tyser & Worley 1992).

<u>Trail type</u>

The observation that total exotic cover, the non-native *C. pycnocephalus*, and the non-native Aster *Sonchus/Crepis* were more prevalent along hiking trails than they were along multi-use trails counters the prediction that multiuse trails will have higher levels of non-natives than do hiking trails. This result could imply that horses and mountain bikes contribute less to the spread of non-native seeds than do hikers. It is interesting to note that during the course of this study, researchers regularly found numerous *C.*

solstitialis seeds embedded in clothing after conducting surveys. This suggests that hikers could potentially play an important role in the dispersal of these seeds.

While the result for *C. pycnocephalus* could be explained by the vulnerability of its erect growth form to damage from trampling on multi-use trails, this explanation may not apply to the unidentified Aster. In the case of the Aster, the plant is characterized by a combination of rosettes accompanied by branched erect stems. Growth form, in this case, is not likely a clear explanation for this species. Rather, the Aster cover was extremely high along one hiking-only trail in Monte Bello. The results for this species (and by implication for total exotics) appear to be largely driven by very high cover at this single site. This large population may in turn be due to this trail's proximity to a parking lot, or some other landscape variable.

Another potentially confounding factor that could contribute to this unexpected result includes illegal trail-use, which could contribute to non-native cover adjacent to so-called hiking trails. On several occasions while surveying along hiking-only trails, researchers witnessed mountain bikes on trail. Therefore, it may be problematic to rely upon existing trails to determine the difference between actual trail uses.

Background variability was also high. The consistent significance of the trail pair factor (block) suggests that native and non-native cover varied considerably from site to site. When choosing sites, I attempted to control for several abiotic factors, such as age of the trail and aspect (all sites generally face southwest). However, the slope of the hillside adjacent to trail pair #2 was more extreme than that of the other pairs. The vegetation on this hillside, particularly above and below the hiking trail, was highly infested with *C. solstitialis*. In fact, cover was seldom below 100%, possibly related to the slope difference.

Another important factor that could influence the outcome of this study included the width of the trails. Multi-use trails generally range from 5 to 10 feet wide while hiking trails are generally 3 feet wide. Wider trails could affect the amount of light, wind, and erosion that penetrates these microhabitats. In addition, District rangers sometimes drive on multi-use trails to patrol the preserves thus adding another potentially significant form of disturbance.

Other Contributing Factors

Results of the correlational study suggest that, at least in this case, other factors may contribute to non-native plant cover more than trail type. Some of these include:

Land use history

Previous land uses likely played a role in introducing some non-native plants to preserves. All study areas were used for cattle grazing until the 1960s and 1970s and some farms, vineyards, and horse stables in the area are still in use. These uses could affect local vegetation in several ways. For example, many of the non-native grasses that dominate the area could have been introduced through animal feed.

Trail construction

Some non-natives could have been introduced during the trail construction process. Heavy machinery used to remove vegetation could help disperse seeds from one site to another. In addition, during the construction of a trail, high levels of disturbance in trailside vegetation could tip the scales in favor of some disturbance-loving exotics.

Feral pigs

Another factor that may affect non-native plant cover is the disturbance provided by feral pigs (*Sus scrofa*). Pigs provide large amounts of localized disturbance in several of the District's preserves and have become a problem in 33 counties in California.

Roads and parking lots

Informal observations suggested that the presence of parking lots and roads influences non-native plant cover, supporting existing literature. Habitat adjacent to parking lots appeared to be particularly invaded by non-native plants.

Experimental Study

<u>Trampling type</u>

The pattern of increased cover with increased disturbance could be explained in the following manner: in my study, physical damage from trampling increases from hikers to mountain bikers to horses; the germination of these species may be positively correlated with the severity of the disturbance. At least three scenarios could offer an explanation for the differential response by *Centaurea solstitialis*, *Geranium*, and *Vicia* to horse disturbance as compared to hiker and mountain biker disturbance. First, lower cover in horse plots could be explained by the high levels of structural damage observed in these plots. As predicted by the intermediate disturbance hypothesis, germination of such species could be fostered by low- and mid-level disturbance but be impeded by high-level disturbance. For example, high levels of trampling may damage seeds of affected species and soil structure. Second, increased erosion during the rainy season caused by horse use could have resulted in the removal of topsoil and certain seeds from the exposed areas.

Manure

The fact that manure did not significantly raise germination rates except when coupled with disturbance implies that the plant community is not structured according to nutrient or seed limitation, but rather competition for light, space, or other factors. The fact that plots that received manure did not generally have significantly elevated cover of non-native herbaceous plants suggests that manure from this particular local stable, is not a major source of exotic seeds.

Other Factors

It is also important to note that the native species that dominated the study sites, *Madia sativa* and *M. gracilis*, are considered by many to be fairly "weedy;" in other words, many *Madia* species are found in disturbed areas. The Skyline region was heavily impacted by grazing in decades past. These conditions likely gave disturbance-loving natives an advantage and may have resulted in the loss of sensitive native species. Thus, the natives found in these preserves are more likely to respond well to trampling experiments. It is quite possible that, had this experiment been carried out in more isolated areas, native cover would have been lower with higher levels of disturbance.

Taken together, surveys of existing trails suggested that native cover decreases closer to trails. This result seems to contradict the results of the trampling study. However, there are several factors associated with the presence of a trail that were not a part of the trampling study. These include: (1) the potential for the introduction and spread of non-native seeds on clothing, fur, boots, tires, and hooves; (2) erosion due to prolonged soil exposure; (3) increased width of trails resulting in more exposure to the sun, wind, and precipitation; and (4) much more frequent and prolonged levels of disturbance.

CONCLUSIONS and RECOMMENDATIONS

This study suggests that some anthropogenic disturbance could be beneficial for at least some native plant populations in areas with a history of disturbance. Any benefit, however, is likely outweighed by the fact that non-native plant cover is also increased by disturbance and that non-natives are far more dominant than are natives under these conditions. In addition, trampling may not positively affect native cover in areas that have historically experienced very little human disturbance. Such pristine sites likely contain more sensitive native species that are less well adapted to disturbance.

The fact that few differences were found in non-native and native plant cover adjacent to hiking versus multi-use trails suggests that the introduction of any trail, even just a hiking trail, could result in non-native plant invasion and the loss of local native plant cover. Therefore, while some disturbance in the form of periodic trampling could benefit some native plant populations, the negative effects associated with the presence of a trail seem to outweigh the biotic benefits.

But trails are an integral part of public open space, and many open spaces would not be preserved without trails. Therefore the following recommendations may assist open space managers and policymakers in prioritizing open space decisionmaking:

Trail Placement

As expanses of land are purchased for preservation and opened to the public by agencies such as the Midpeninsula Regional Open Space District, it is necessary to place trails in areas less likely to be heavily impacted by recreation. Sensitive habitats and sites with significant populations of native plants should be avoided for both multi-use and hiking trails. While conducting surveys and looking for study sites, it became apparent that, while grasslands were heavily impacted by invasive forbs and grasses, woodlands and chaparral were largely unaffected in comparison. This leads to the conclusion that grasslands and coastal prairie may be more susceptible to non-native plant invasion. Therefore, it may be preferable to locate new trails in wooded areas where fewer non-native plants introduced by trail-users can establish. This could be particularly true if there are sensitive native species in the area. Sensitive grassland habitats could potentially be destroyed by the introduction of aggressive non-natives such as *C. solstitialis*.

This conclusion, however, is complicated by the recent introduction of *Phytophthora ramorum,* which causes a disease often referred to as Sudden Oak Death. This pathogen infects woodland and forest species and is likely spread by trail-users. Its growing prevalence may necessitate keeping trail-users out of many wooded areas.

Management

There is a general understanding that once land is purchased by a conservation organization, the local flora and fauna are permanently preserved. In reality, in order for that land to continue to be valuable wildlife habitat, considerable care must be taken to manage it effectively. For example, non-native plants can invade an ecosystem, changing ecosystem processes and displacing the native plants that local wildlife depends upon, potentially degrading the value of habitat. In order to tackle these obstacles, it must be widely recognized that open space management, and particularly non-native species control, must be a high priority.

In the case of *Centaurea solstitialis*, its containment could involve using trail signage and brochures to educate trail-users about the importance of checking for seeds before and after hiking in a preserve. This should not be too difficult because the plant is easily identifiable and its thorns make it unpopular among avid trail-users.

With respect to deciding which types of trail use to allow, restricting trail-use to allow only hikers may not be necessary to prevent non-native plant invasion. As stated earlier, the affect of any trail may be significant. However, the literature suggests that caution should be exercised when deciding what uses to allow in erosion prone areas, such as steep trails and riparian areas. Studies indicate that these areas may be more suited to hikers, which generally cause less erosion than horses and motorcycles. Very little information, however, is available in the scientific literature regarding the effects of mountain bikes on erosion because the sport is quite new. Certainly there is a need to study this effect further.

It is imperative that land managers carefully monitor the effects of their management activities on a species by species basis. If trail use appears to be promoting the spread of invasive plants or pathogens, periodic or seasonal trail closures could be considered. Certainly this study indicates the need for regular monitoring of erosion and other soil disturbance, as well as the control of illicit trail use through volunteer and enforcement activities.

Future Studies

The scope of this study was a small part of a larger question: how can we stop the spread of invasive exotic plants? While these results suggest that both hiking and multi-use trails affect non-native cover, it would be useful to clarify the role of the trail-user in the dispersal of non-native seeds. This could be accomplished by monitoring the number of seeds present on hikers, mountain bikers, horses, and dogs after traveling through a preserve. Such a study could imply that simple steps, such as cleaning one's boots before entering a preserve, may go a long way in containing some species.

In addition, the effects of trails on non-native and native plant cover could also be studied by comparing patches of grassland with and without trails. This could further clarify the degree to which non-native plant cover is influenced by the presence of trails.

Other sources of seeds should be investigated as well. For example, MROSD and other open space agencies could conduct a large-scale correlational study comparing exotic plant cover and proximity to trail heads, parking lots, and roads by utilizing existing volunteers.

Another potential study could investigate whether a species that has invaded a preserve originated from one or more separate introductions. Such a study would include

DNA analysis of non-native plant populations throughout a preserve and at potential source locations, such as parking lots and trail heads.

Such information is vital as agencies and non-profits scramble to acquire and protect lands from development and subsequently open them to the public for "low impact" recreation. For these areas to be truly protected, we must seek a greater understanding of how our management practices impact the land we are fighting to preserve.

If we do not find answers to these questions in the near future, we could lose our unique natural communities to a handful of aggressive cosmopolitan species. Such a scenario would not only mean fewer species for us to enjoy but also a degraded landscape with little value to wildlife. California is losing its wildlands at an alarming rate; it would be a tragedy to save our lands from the bulldozer only to lose them to invasive species.

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APPENDICES

Appendix A. Data Sheet: Correlational Study

Researcher: ______________________________ Date/time: ____________________

Trail segment: SR-H1 SR-H2 SR-H3 MB-H1

SR-M1 SR-M2 SR-M3 MB-M1

Transect location: ______________________ Distance from trail: 1 2 4 8 16

Slope: ______________________ Aspect: ________________________________

Species; Identification information; Sample #	Native/ Exotic	Total Cover (# of 5cm incr.)
GRASSES	E	
YELLOW STAR THISTLE (*Centaurea solstitialis*)	E	
ITALIAN THISTLE (*Carduus pycnocephalus*)	E	
MUSTARD (*Hirschfeldia incasa*)	E	
COAST TARWEED (*Madia sativa*)	E	
HARDING GRASS (*Phalaris aquatica*)	E	
SOWTHISTLE (*Sonchus* spp)	E	
Misc Herbs		
GOPHER MOUND		
BARE GROUND		

Appendix B. Data Sheet: Trampling Study

Date:__________ Researchers:____

Site: A B C D E F (circle one)

Control Hiker Mountain Bike Horse Manure + Disturbance Manure

Enter # ***Squares (1-100) / Cover Class estimate*** (A: <5%; B: 5-24%; C: 25-49%; D: 50-74%; E: >75%)

Grass spp	/	
Bare ground	/	
C. solstitialis	/	
Geraniaceae	/	
Sisyrinchium bellum	/	
Sanicula spp.	/	
Rumex acetosella	/	
Erodium botrys	/	
Medicago lupulina	/	
Ranunculus	/	
Lotus purshianus		
Lotus (other)	/	
Amsinckia menziessii	/	
Plagiobothrys	/	
Vicia spp	/	
Plantago lanceolata	/	
Viola	/	
Juncus	/	
Cerastium	/	
Trifolium	/	
Lupinus (nanus etc.)	/	
Anagallis arvensis	/	
Sherardia arvensis	/	
Sonchus spp	/	
Asteraceae	/	
Dipsacus (teasel)	/	
Wyethia glabra	/	
	/	
	/	
	/	
	/	
	/	
	/	

Appendix C. Shannon-Weiner diversity index value (H') for each trampling type. Values listed include homogeneity and standard error around the mean. Native species cover tended to be less diverse than non-native cover. Exotic species cover in hiking plots was significantly more diverse than in horse plots ($p = 0.025$).

	Control		Hiker		Mountain Bike		Horse	
	H'	SE	H'	SE	H'	SE	H'	SE
Native	0.47	0.06	0.45	0.07	0.44	0.07	0.41	0.05
Non-native	0.97	0.07	1.07	0.05	1.05	0.08	0.92	0.03

Appendix D. Figures

Figure 1. Location of study sites in the San Francisco Bay Area, California.

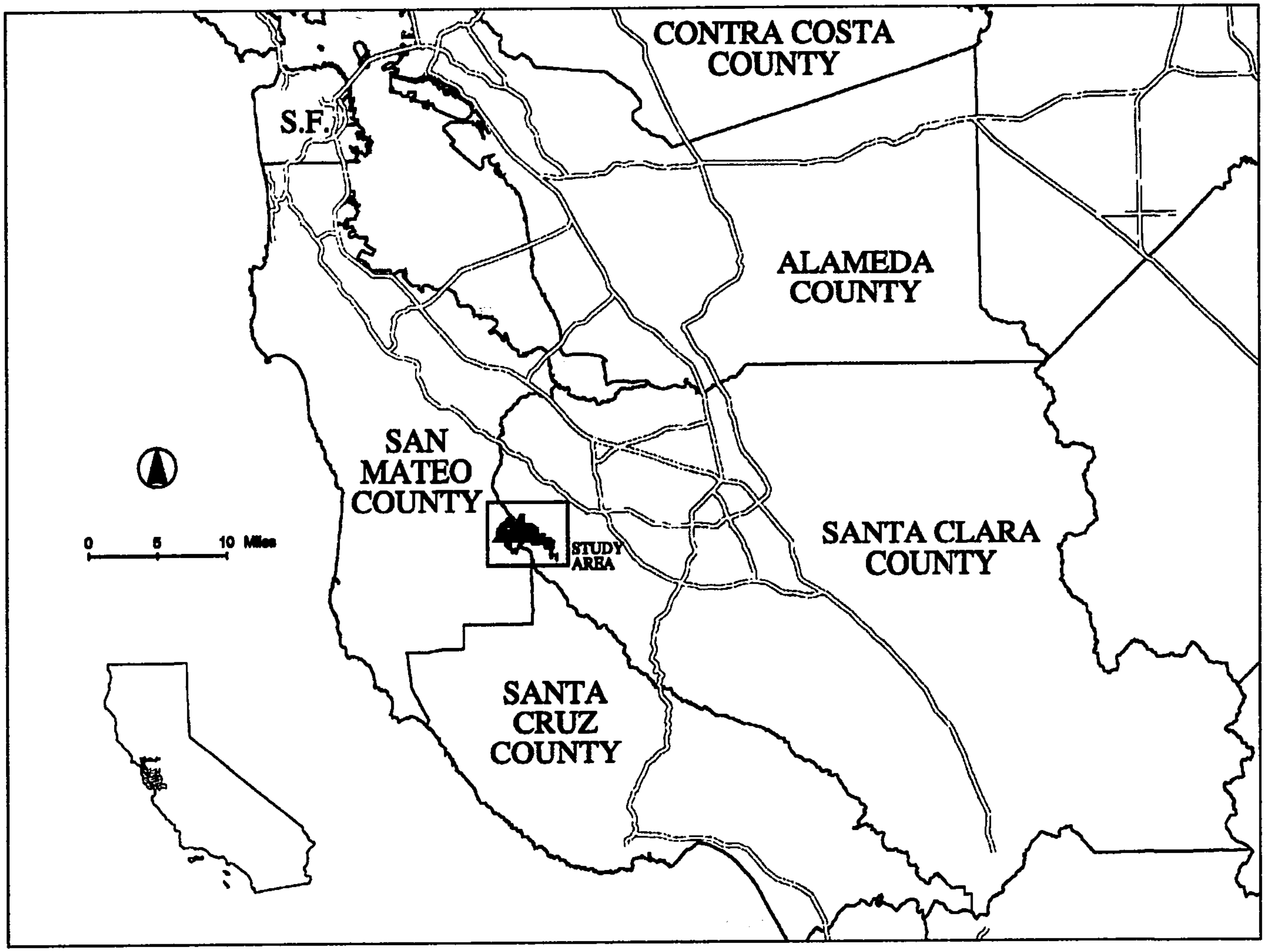

Figure 2. Locations of study sites in Monte Bello and Skyline Ridge Open Space Preserves for correlational and experimental study.

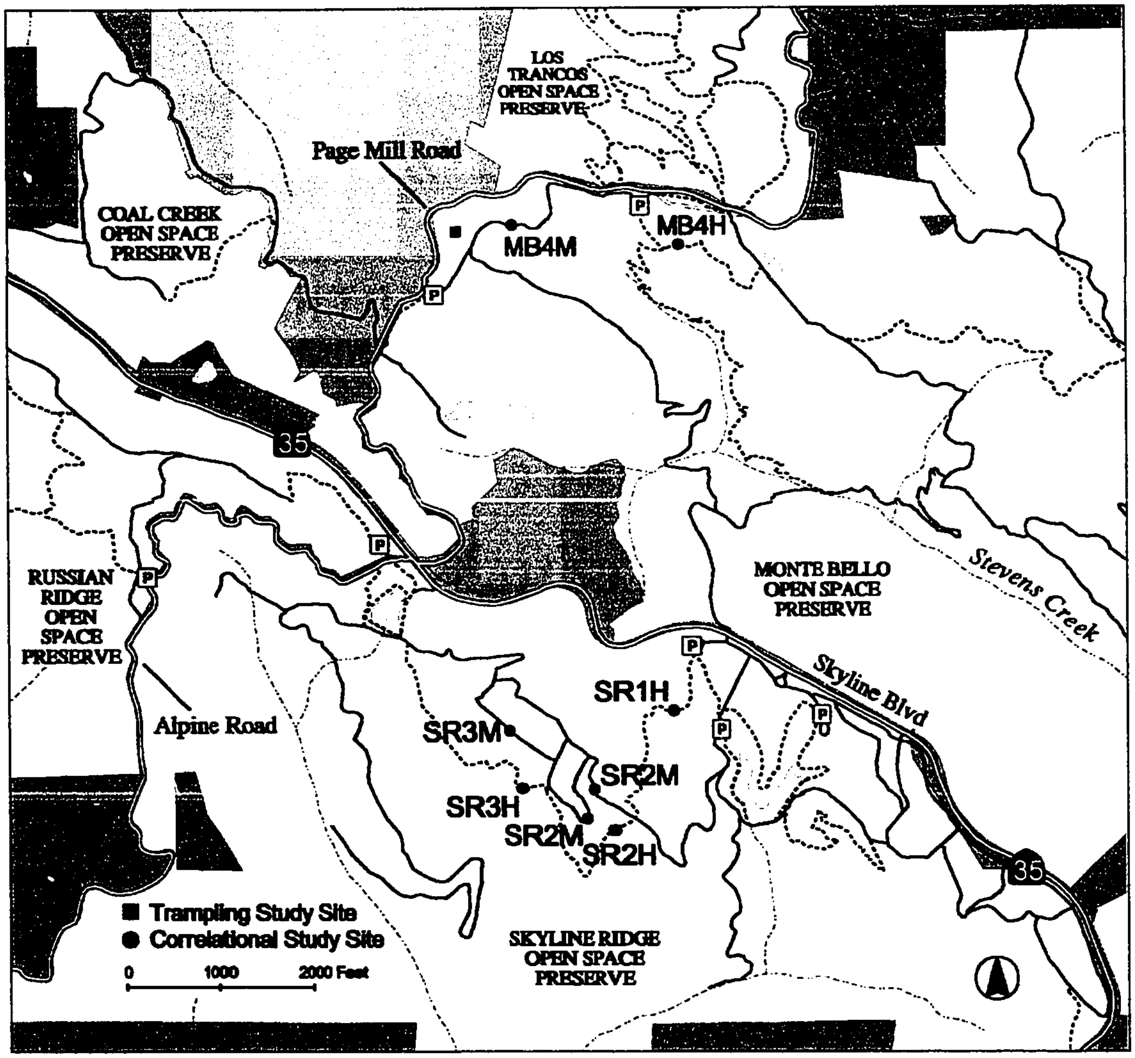

Figure 3. Relief map of study area.

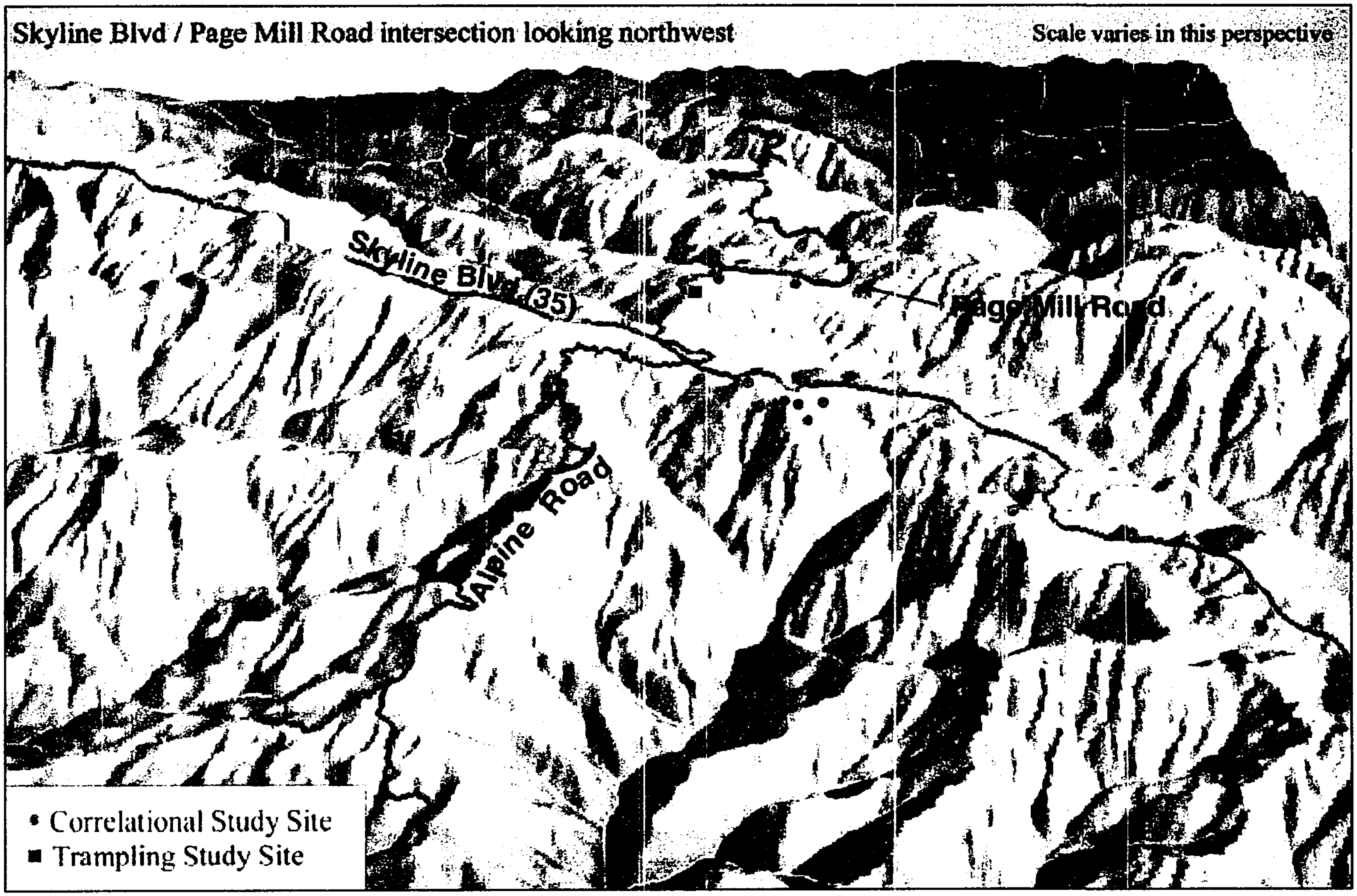

Figure 4. Hiking trail in trail pair 1, located in Skyline Ridge Open Space Preserve.

Figure 5. Multi-use trail in trail pair 1, located in Skyline Ridge Open Space Preserve.

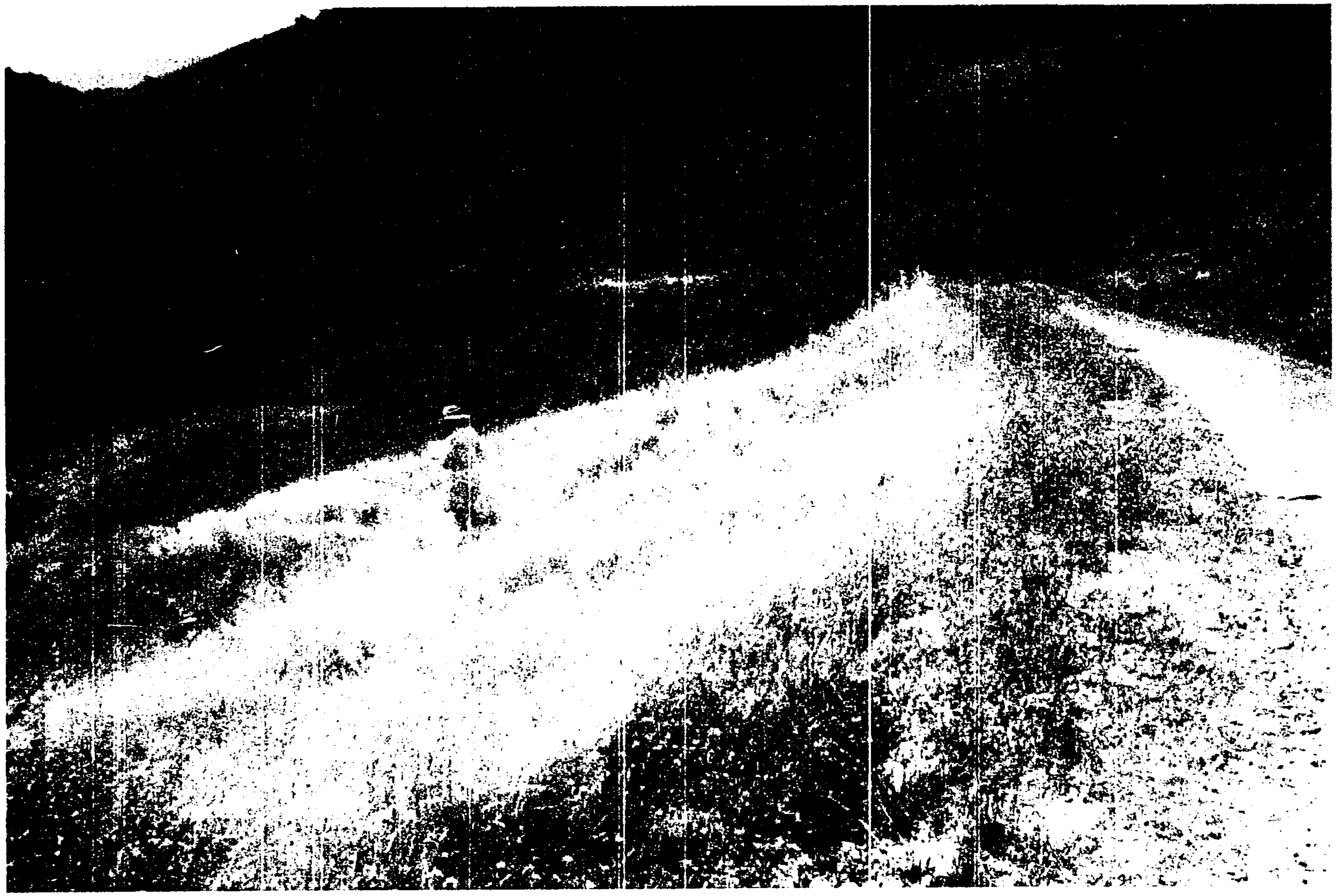

Figure 6. Hiking trail in trail pair 2, located in Skyline Ridge Open Space Preserve.

Figure 7. Multi-use trail in trail pair 2, located in Skyline Ridge Open Space Preserve.

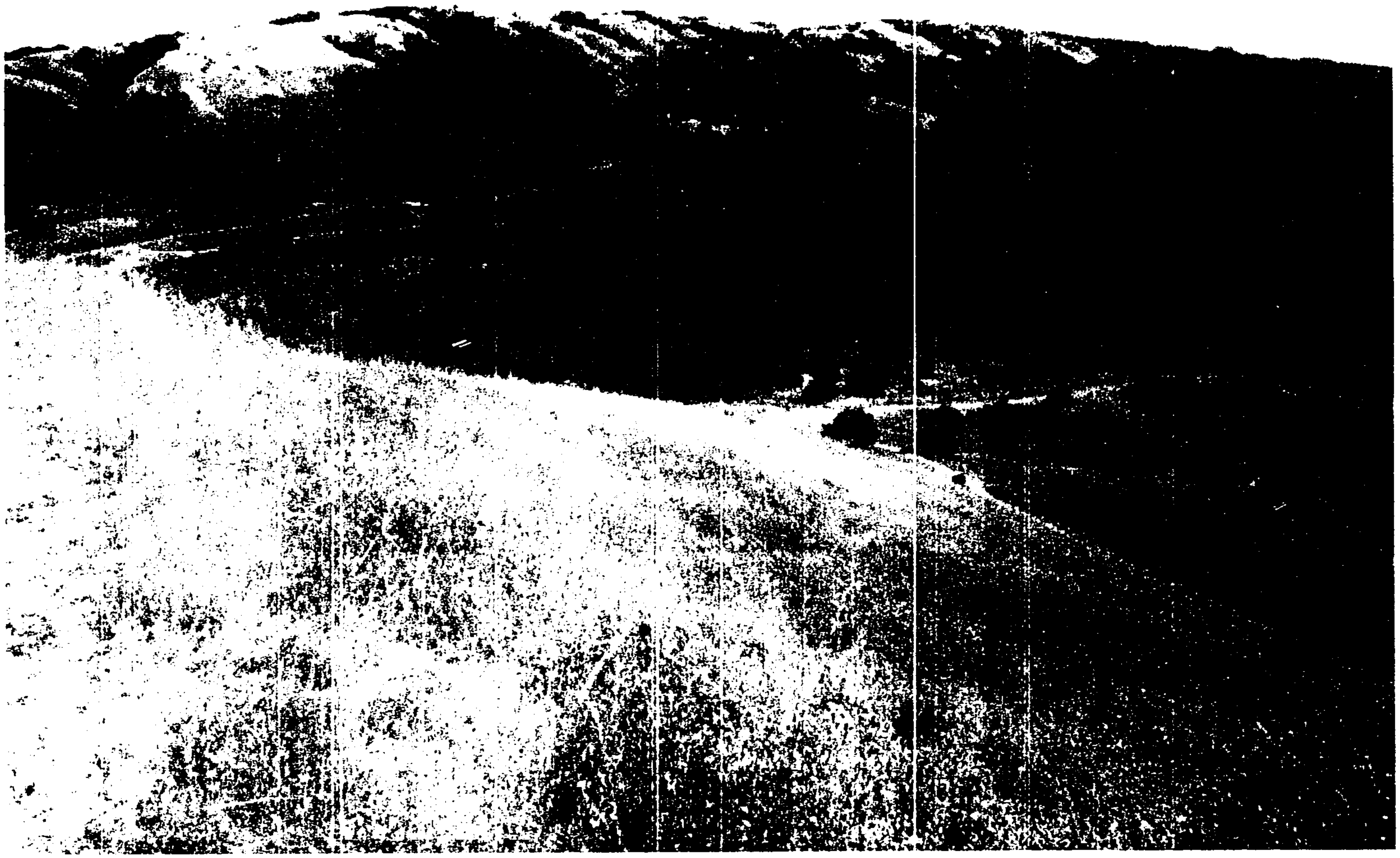

Figure 8. Hiking trail in trail pair 3, located in Skyline Ridge Open Space Preserve.

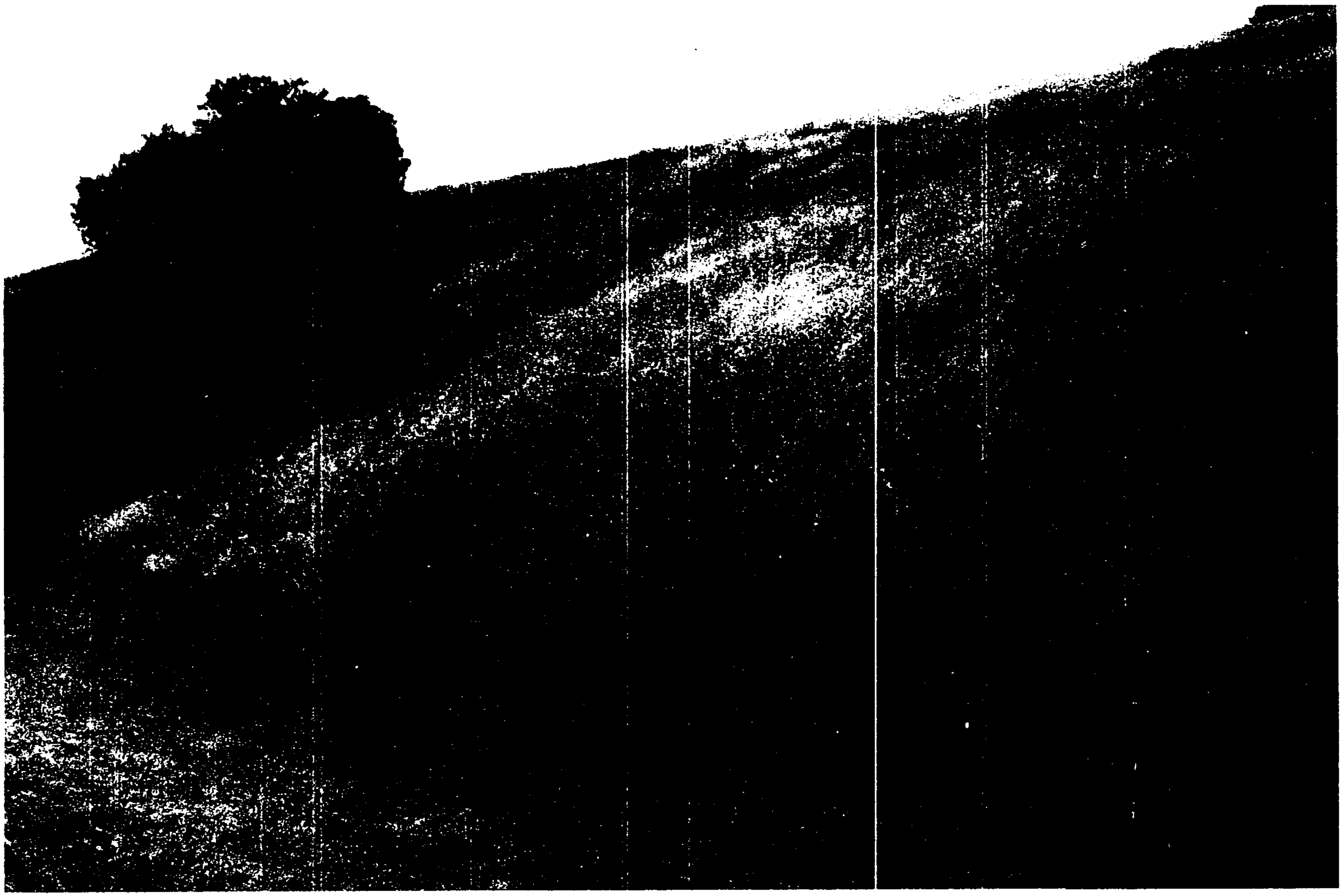

Figure 9. Multi-use trail in trail pair 3, located in Skyline Ridge Open Space Preserve.

Figure 10. Hiking trail in trail pair 4, located in Monte Bello Open Space Preserve.

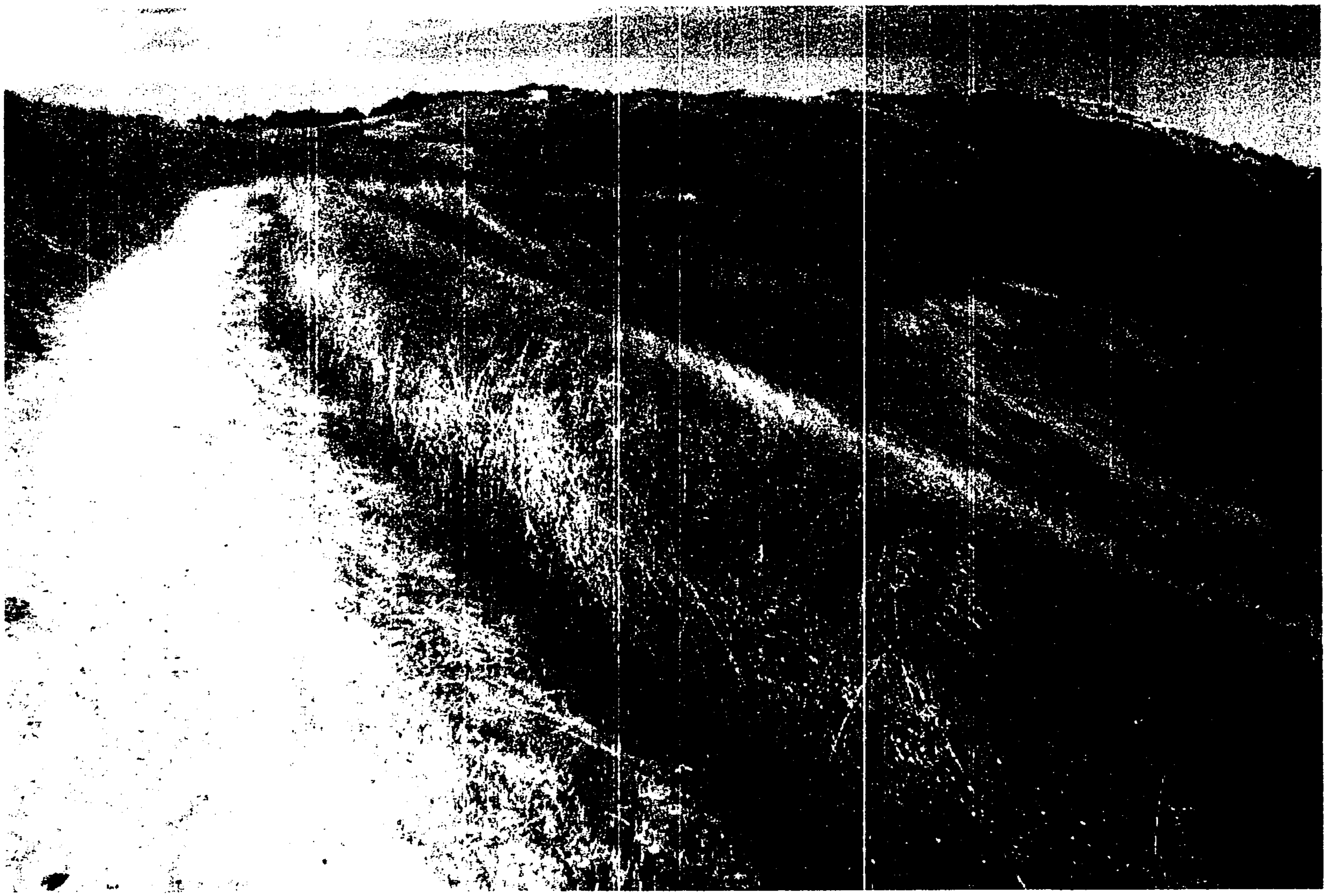

Figure 11. Multi-use trail in trail pair 4, located in Monte Bello Open Space Preserve.

Figure 12. Trampling study site at Monte Bello Open Space Preserve.

Figure 13. *Centaurea solstitialis* (yellow star thistle).

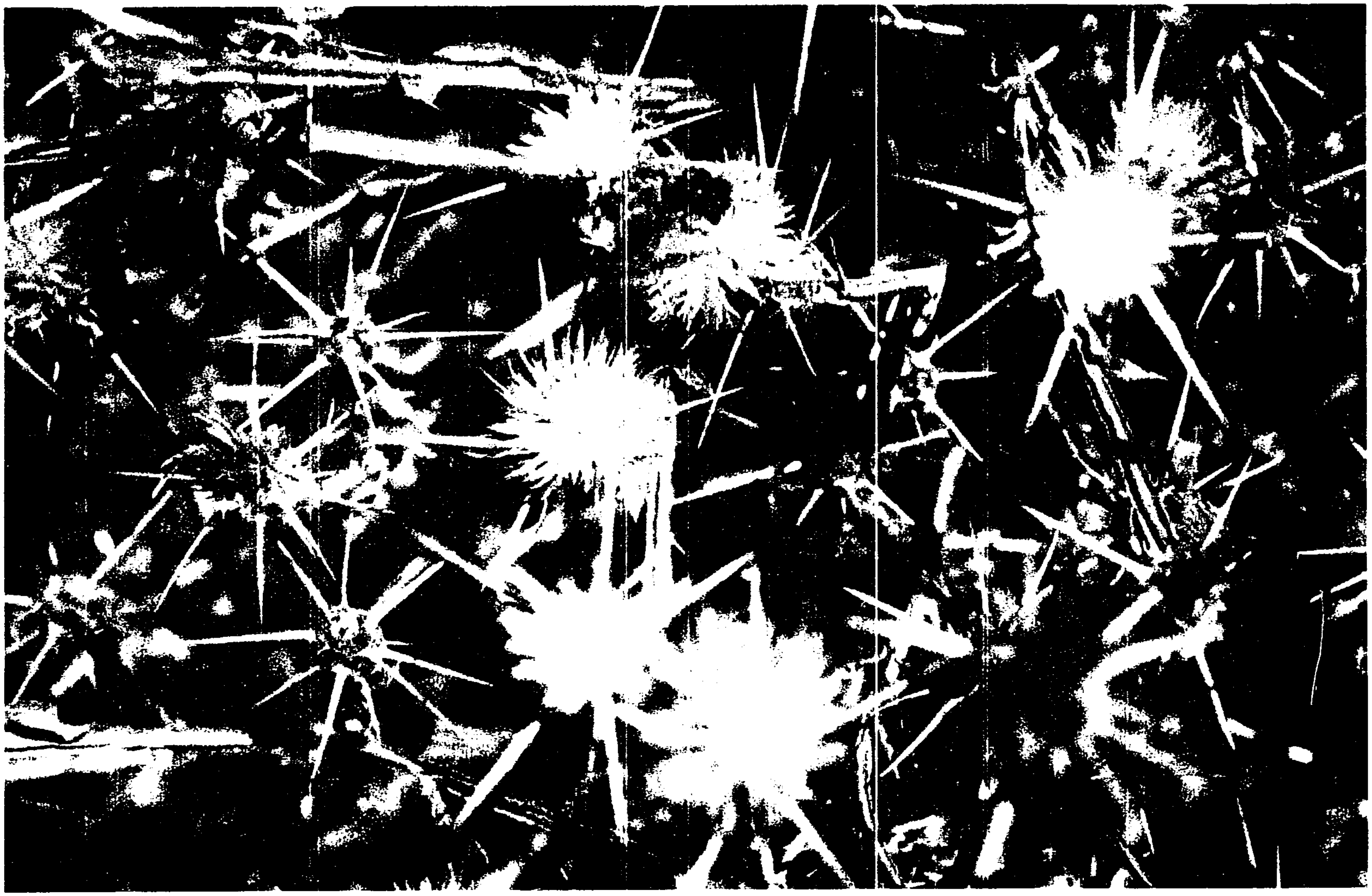

Figure 14. Total mean percent cover of native species at varying distances from the trail edge, using both hiking and multi-use trail data. Total percent cover of native species was calculated by summing covers for *Madia* species, *Lupinus* species, *Trichostema lanceolatum*, *Amsinckia* species, and *Eremocarpus setigerus* for all plots 1, 2, 4, 8, and 16 meters from the trail edge. ANOVA and post-hoc comparisons of means (paired contrasts) revealed two significant differences between groups. Native cover at 2 meters was significantly higher than was native cover at 1 meter ($p = 0.028$). Cover at 16 meters was also significantly higher than cover at 1 meter ($p = 0.007$). Cover at 16 meters tended to be higher than cover at 4 meters but this difference was only a trend ($p = 0.059$). $N = 8$. Error bars reflect standard error around the mean.

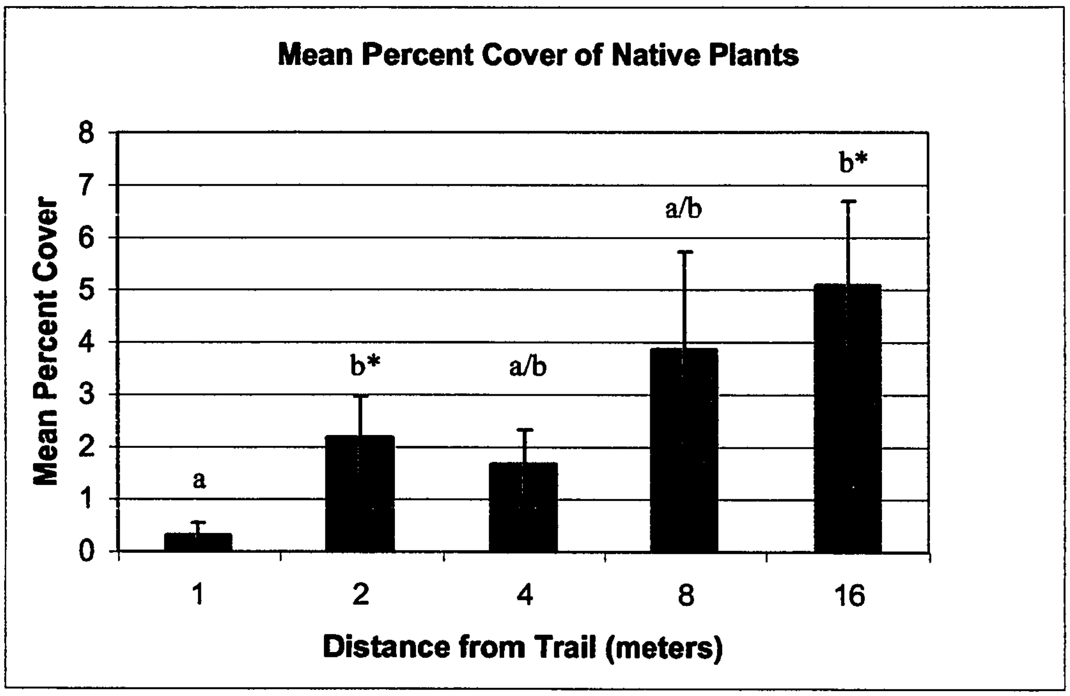

Figure 15. Mean percent cover of *Carduus pycnocephalus* (Italian thistle) at 1, 2, 4, 8, and 16 meters from the trail edge. One-way ANOVA post-hoc pair-wise comparisons show a significant difference between cover at 2 meters and 8 meters (p = 0.047). Cover at 2 meters tended to exceed cover at 4 meters (p = 0.078) and 1 meter (p = 0.097). N = 8. Error bars reflect standard error around the mean.

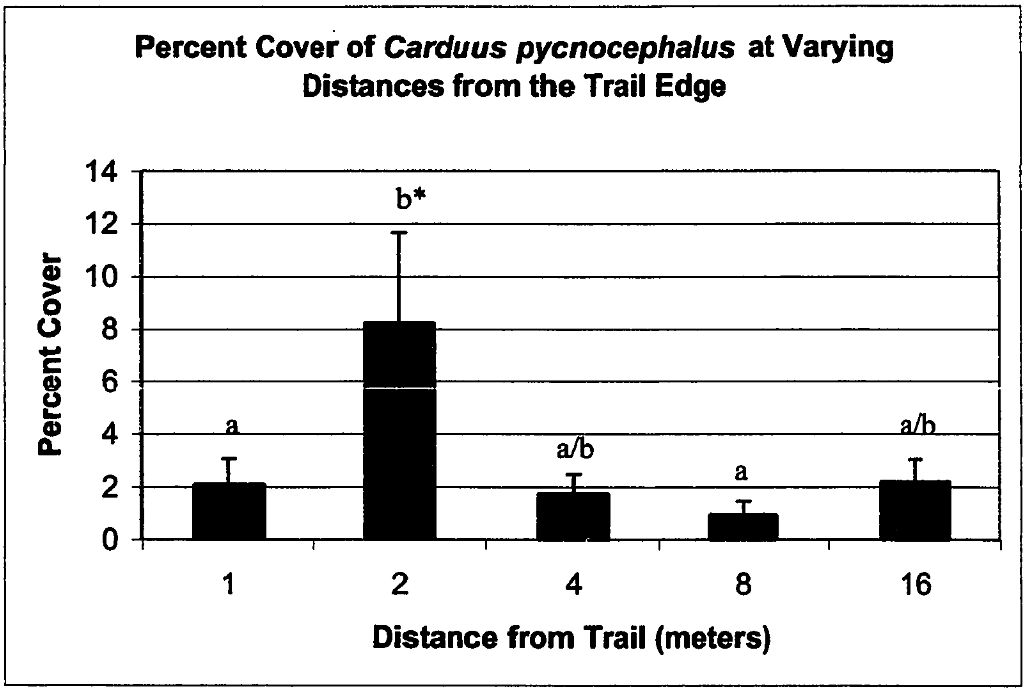

Figure 16. Mean percent cover of species that are less prevalent adjacent to multi-use trails than hiking trails. ANOVA suggests that mean total exotic percent cover is significantly higher along hiking trails than multi-use trails ($p = 0.024$). In addition, *Carduus pycnocephalus* (Italian thistle) ($p = 0.012$) and *Sonchus/Crepis* species (sow thistle/hawk's-beard) ($p = 0.052$) were significantly higher along hiking trails. Total exotic cover along hiking trails is not significantly different from that along multi-use trails if *Sonchus* is excluded. N = 8. Error bars reflect standard error around the mean.

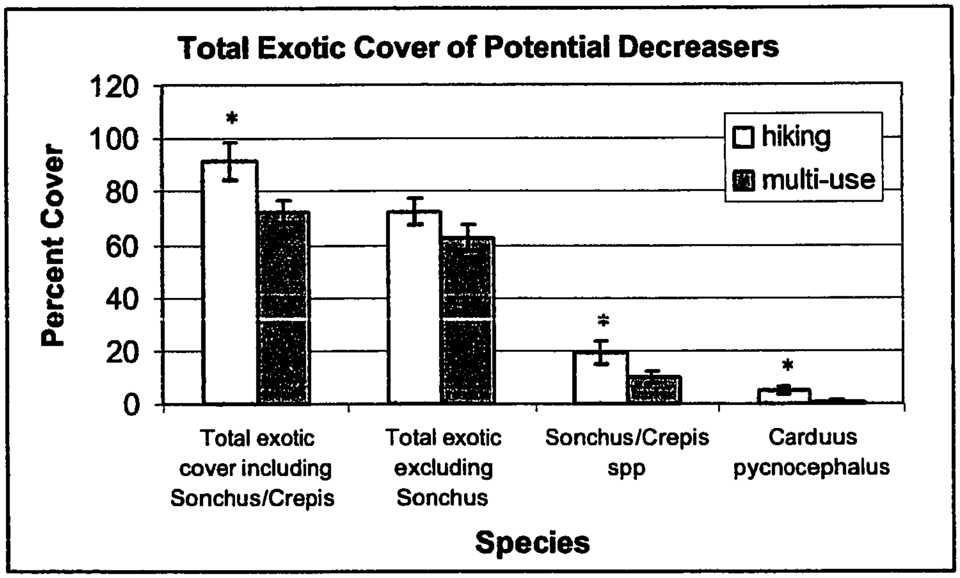

Figure 17. Mean percent cover of grasses along hiking trails and multi-use trails. Grass cover was significantly higher along multi-use trails than hiking trails ($p = 0.000$). $N = 8$. Error bars represent standard error around the mean.

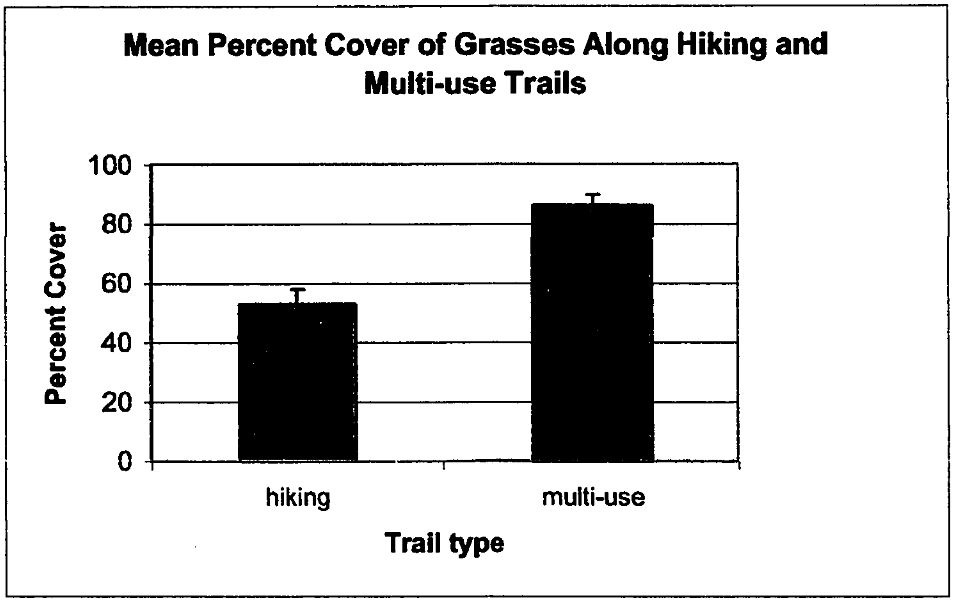

Figure 18. The effect of block was investigated using General Linear Model univariate tests of between-subject effects for *Centaurea solstitialis* cover along hiking and multi-use trail pairs by block. Variation between blocks was significant (p = 0.000). There was no significant difference between hiking and multi-use trails for *C. solstitialis* (p = 0.230).

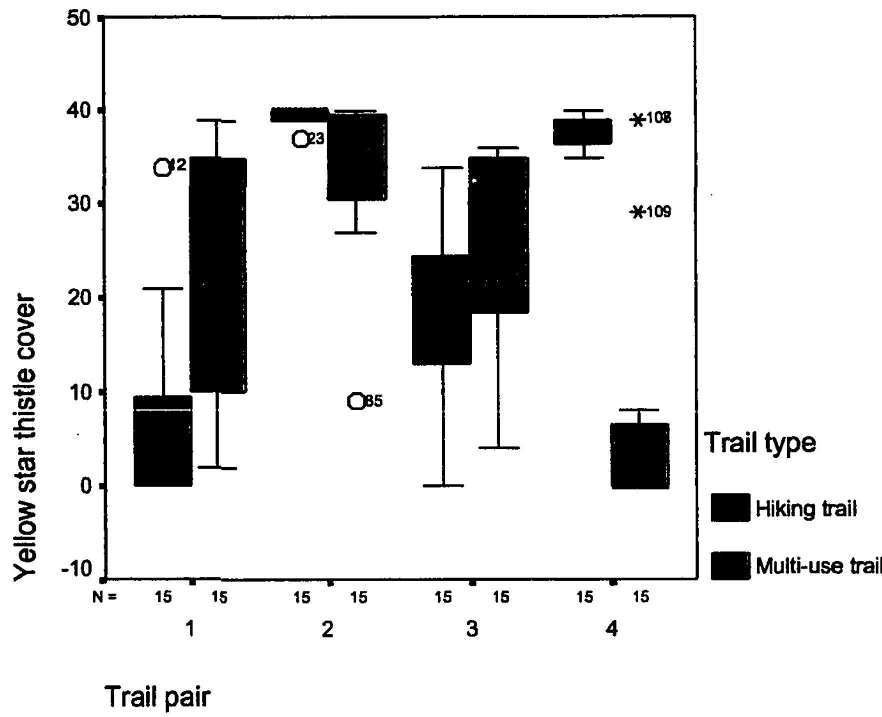

Figure 19. Effect of trail pair on total exotic cover. Cover includes that of the unidentified Aster (*Sonchus* or *Crepis* species).

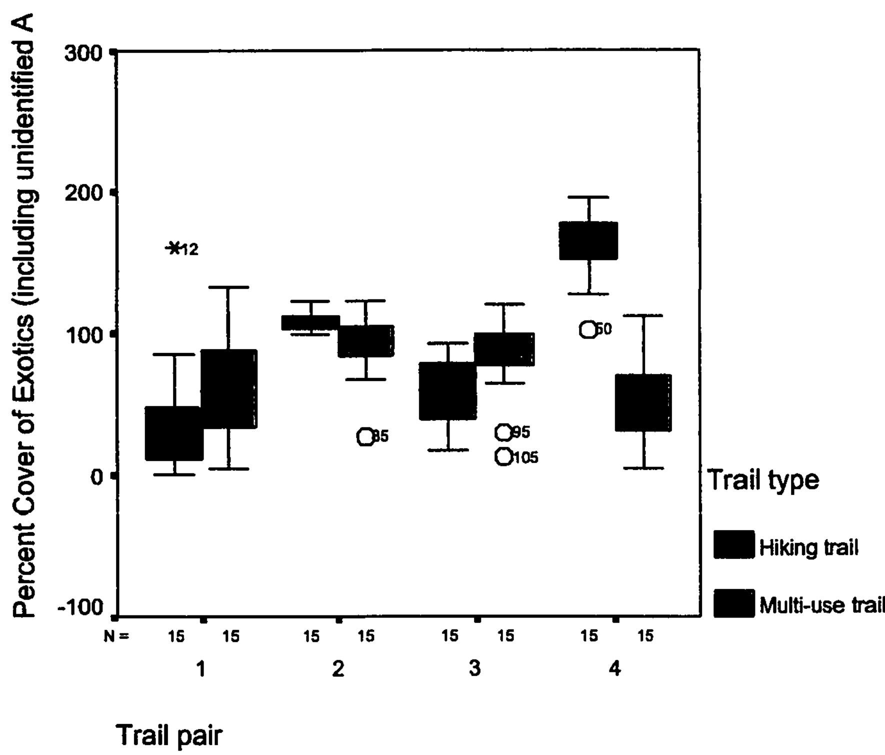

Figure 20. The effect of block on cover of the unidentified Aster (*Sonchus* or *Crepis* species). Cover was higher in pair 4 than any other pair (p = 0.000 for all comparisons).

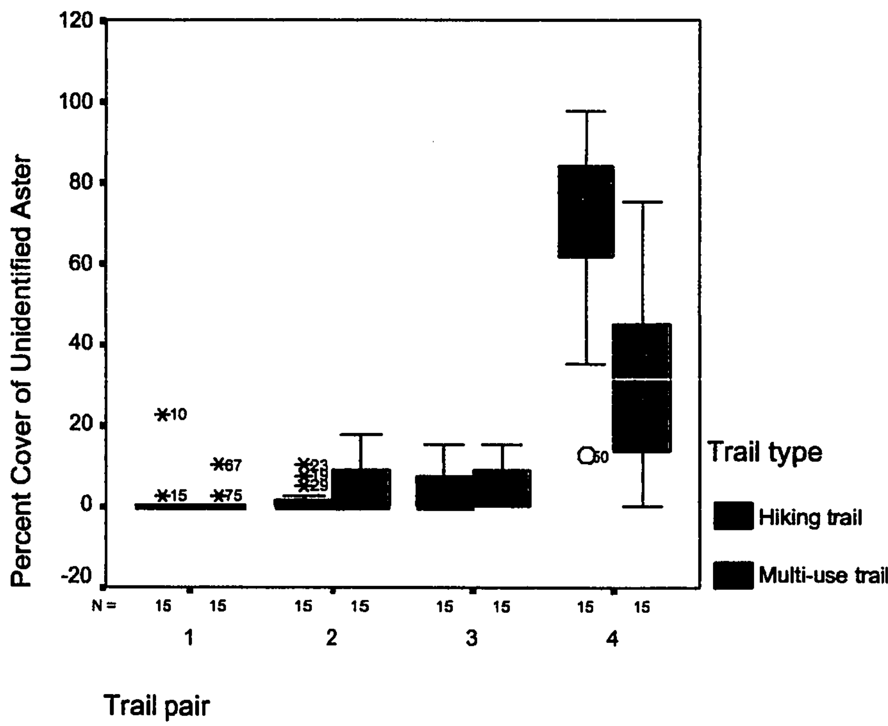

Figure 21. Effect of trail pair on percent cover of total exotics (excluding the unidentified Aster at pair 1).

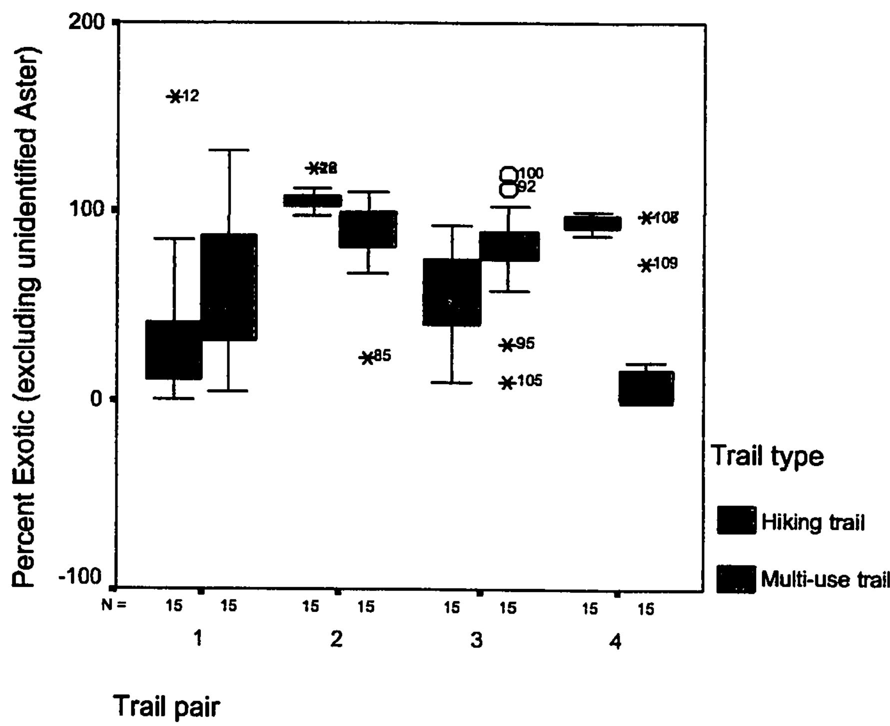

Figure 22. Effect of block on percent cover of non-native grasses. Cover was highest in pair 3 than all others (p = 0.000), higher in pair 1 than pair 2 (p = 0.000), and higher in pair 4 than pair 2 (p = 0.000).

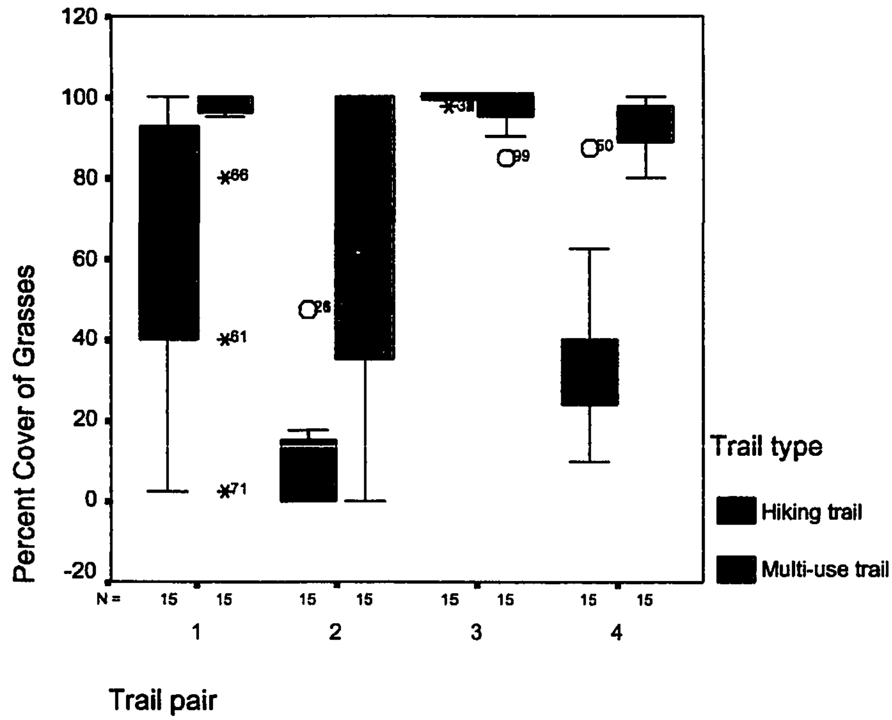

Figure 23. Effect of block on total percent cover of native herbaceous species. Native cover was higher in pair 1 than all others (p = 0.000).

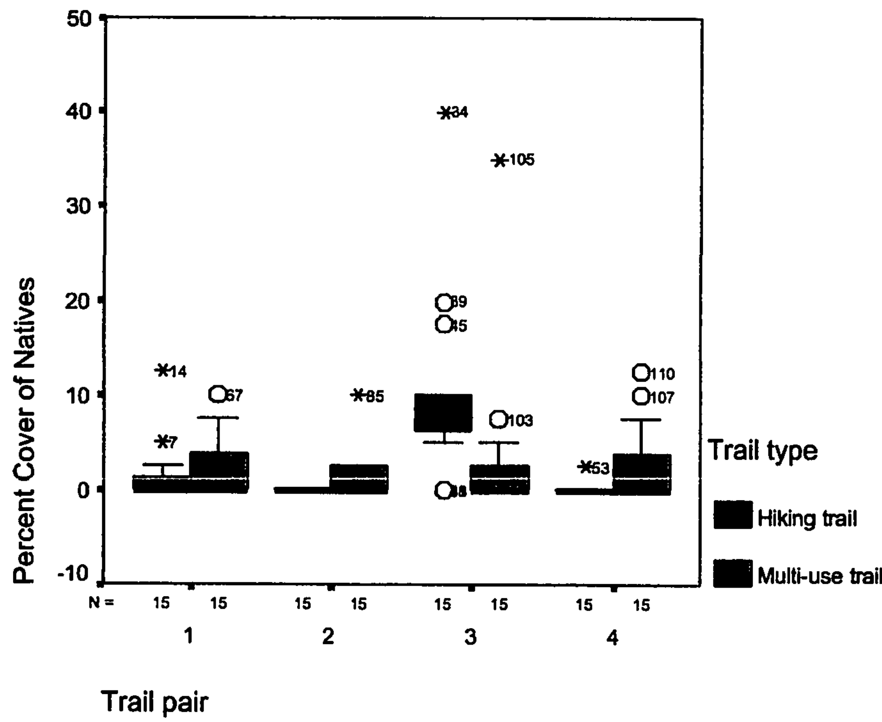

Figure 24. The effect of block on *Madia* cover. Cover was significantly higher in pair 3 than in other pairs (p = 0.000 for all).

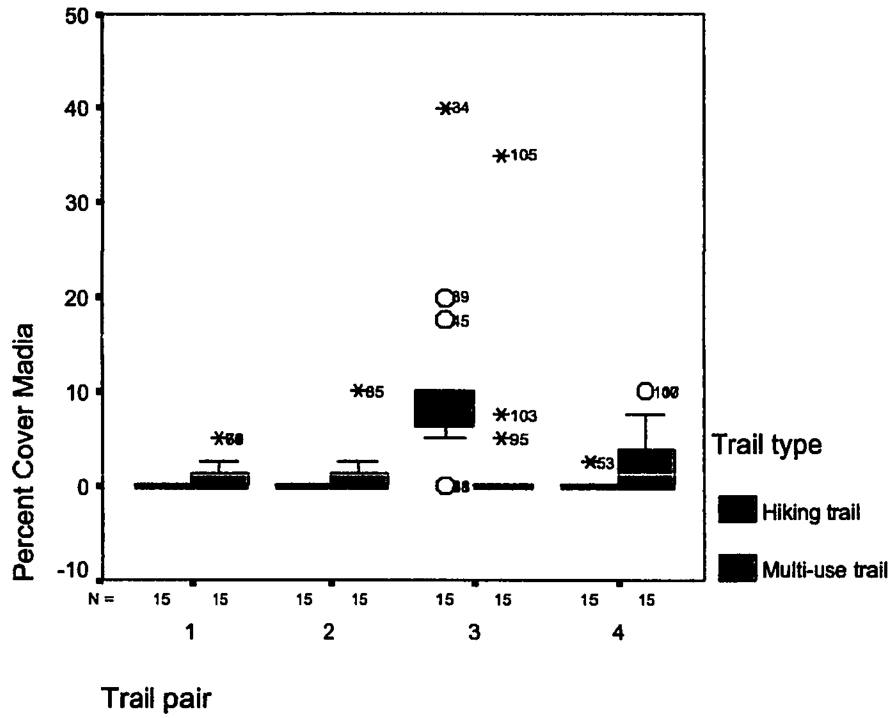

Figure 25. Effect of block on cover of gopher mounds. Cover in pair 4 exceeded that of all other pairs (p = 0.000 for all comparisons).

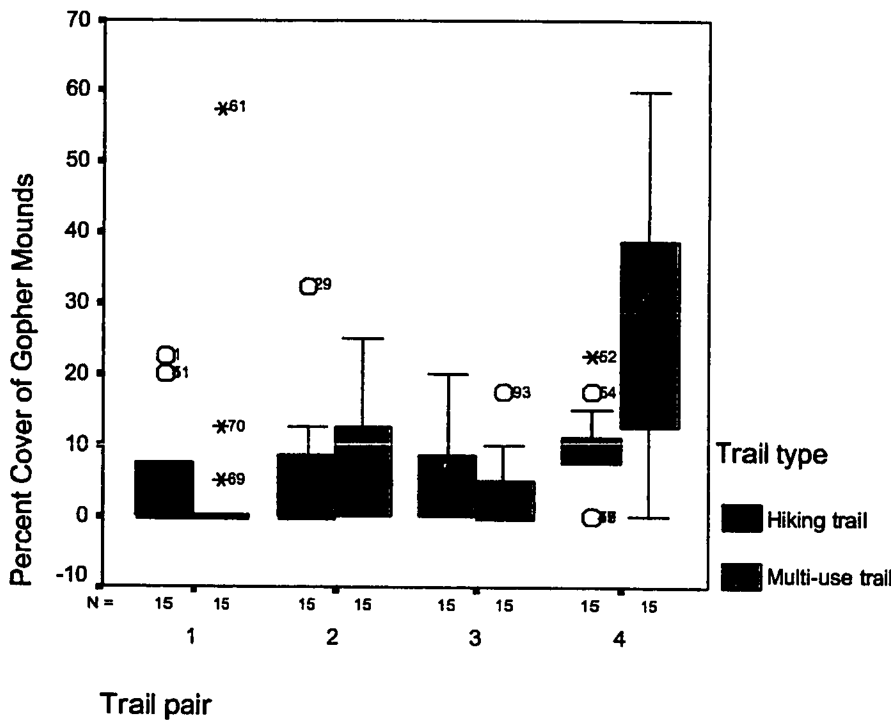

Figure 26. One 3 x 0.5 meter plot after receiving 40 passes by a hiker.

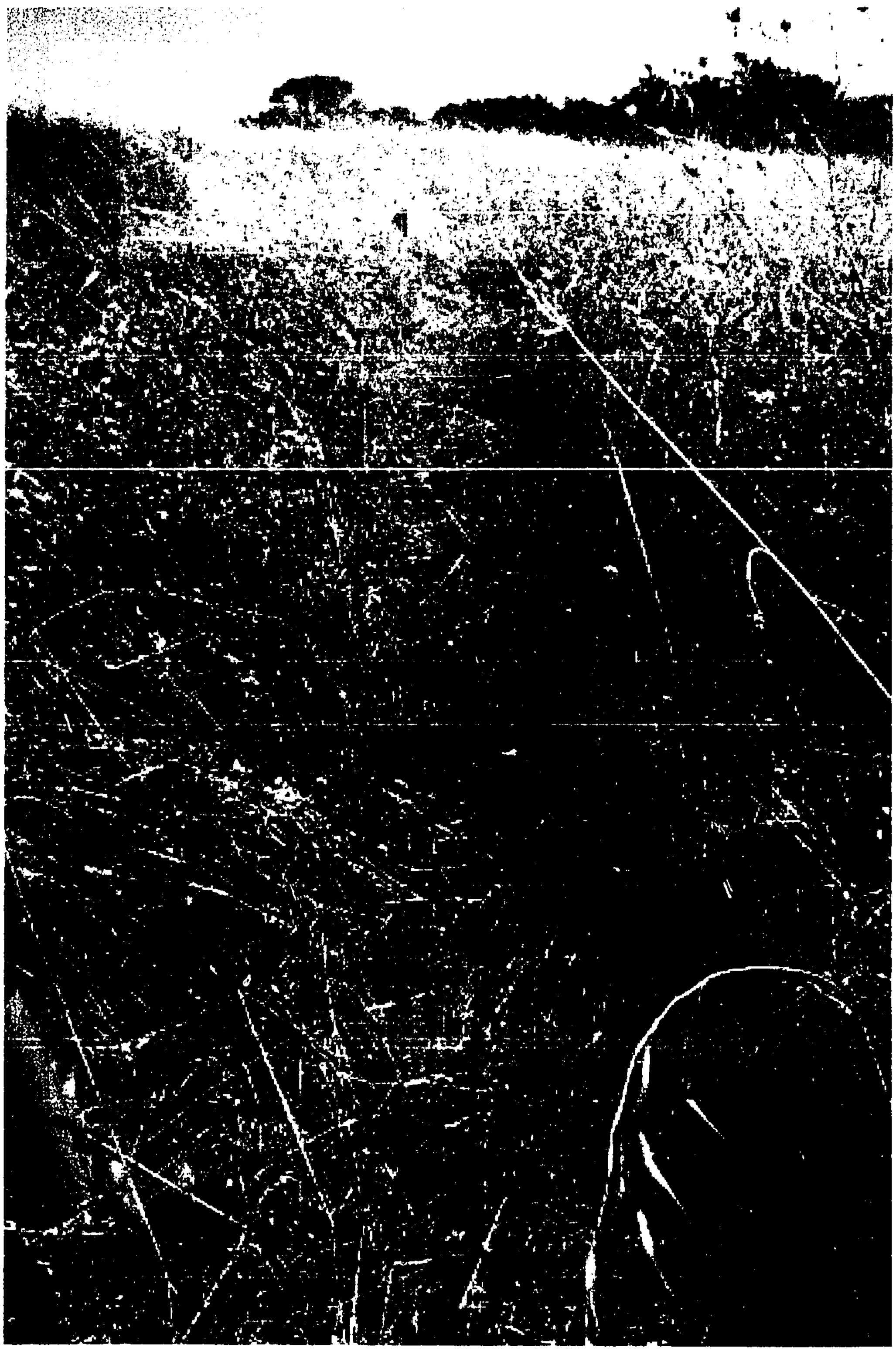

Figure 27. One 3 x 0.5 meter plot after receiving 40 passes by a mountain bike.

Figure 28. One 3 x 0.5 meter plot after receiving 40 passes by a shod horse and rider.

Figure 29. Mean percent cover of non-native species that increased with disturbance. One-way ANOVA and post-hoc comparisons of means (paired contrasts) indicated that *Anagallis arvensis* cover was significantly higher on horse plots than control ($p = 0.026$). *Linum bienne* cover was significantly higher on horse plots than control (0.008) and significantly higher on plots with manure and disturbance than plots with just manure ($p = 0.052$). *Medicago lupulina* cover tended to be higher on horse plots than control plots ($p = 0.087$). Significant differences from the control are indicated by an asterisk. N = 6. Error bars indicate standard error around the mean.

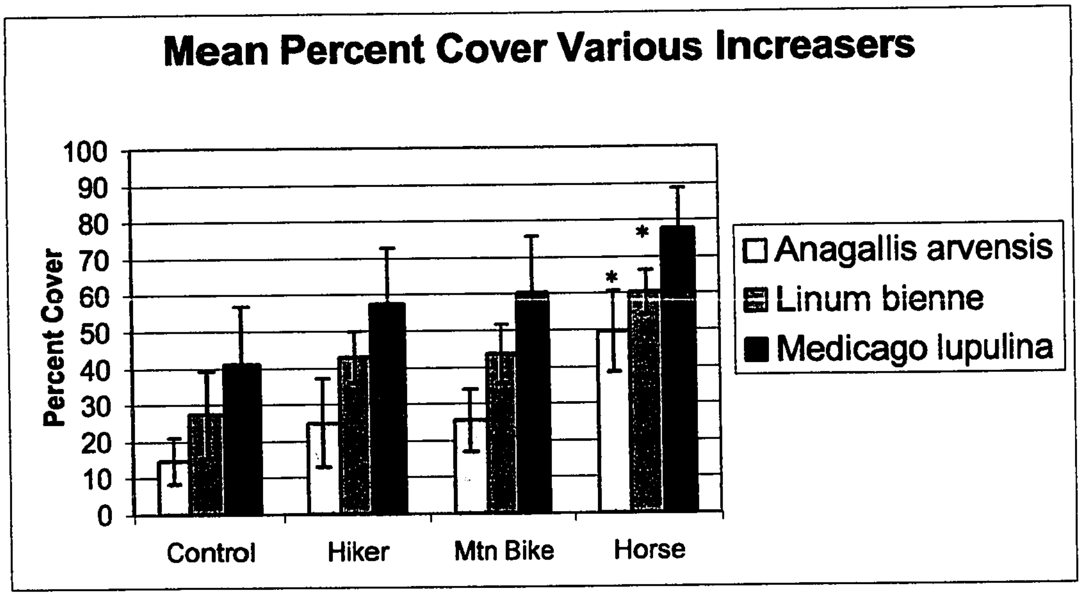

Figure 30. Percent cover of *Anagallis arvensis* (scarlet pimpernel). Cover was significantly higher in plots trampled by a horse than control plots (p = 0.026). N = 6. Error bars represent standard error around the mean.

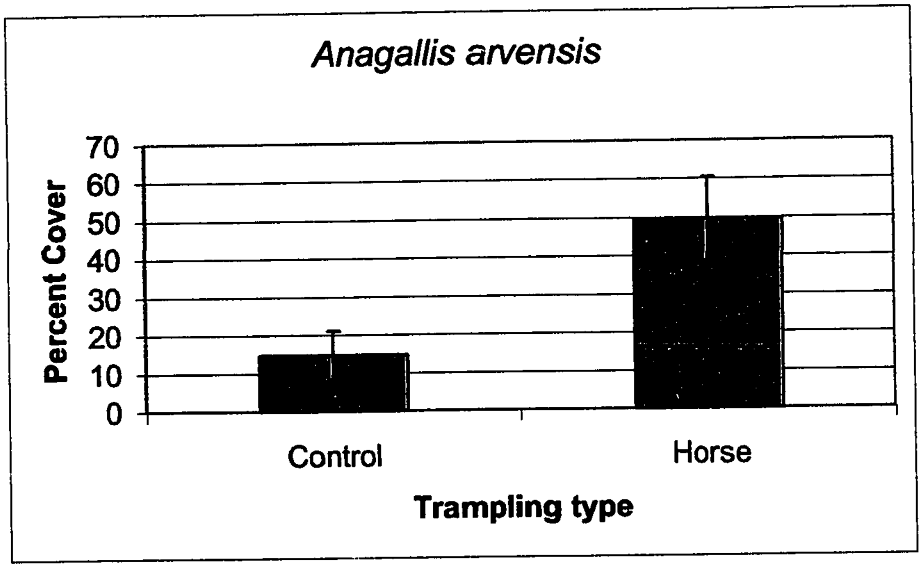

Figure 31. Percent cover of *Medicago lupulina* (black medick). Cover in plots trampled by a horse tended to be higher than control plots ($p = 0.087$). $N = 6$. Error bars represent standard error around the mean.

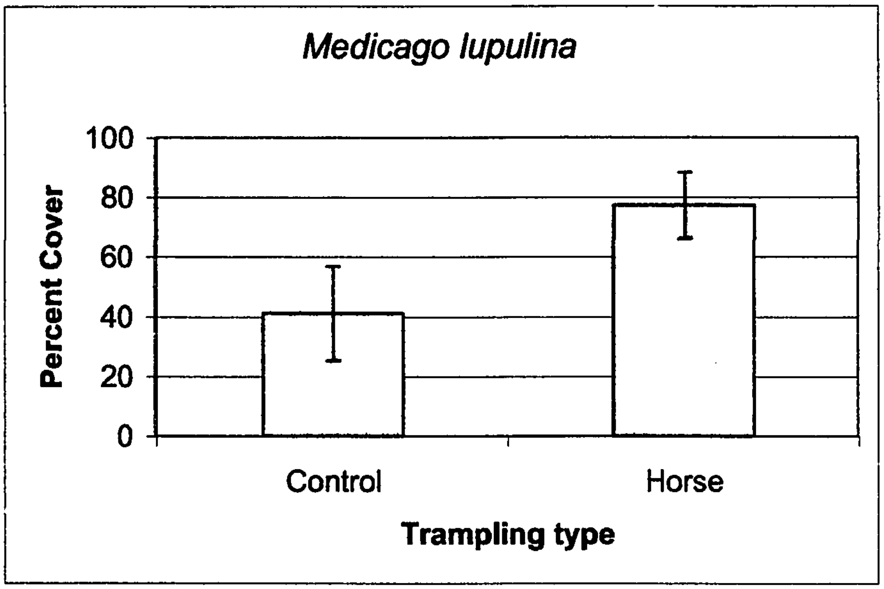

Figure 32. Percent cover of *Linum bienne* (narrowleaf flax). Cover was significantly higher in horse plots than control ($p = 0.008$). N = 6. Error bars represent standard error around the mean.

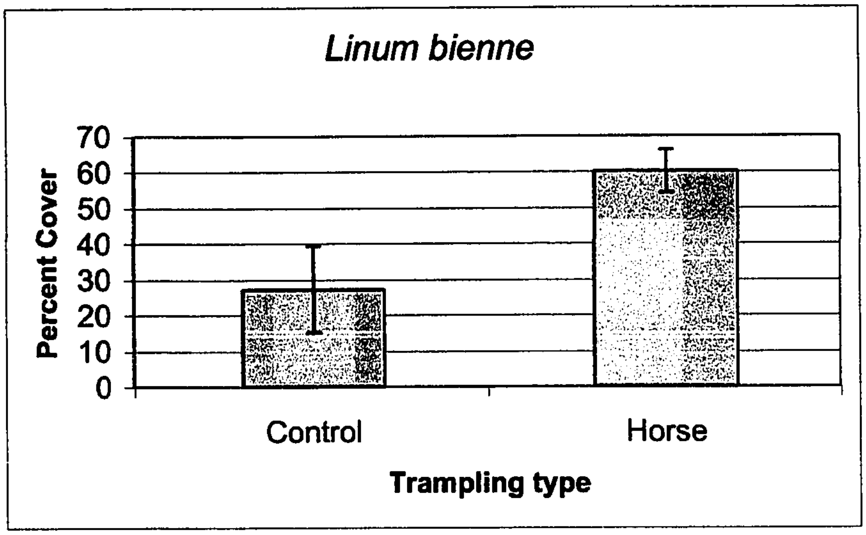

Figure 33. Percent cover of *Linum bienne* (narrowleaf flax). Cover tended to be higher in plots that received manure and disturbance than plots that received only manure ($p = 0.052$). N = 6. Error bars represent standard error around the mean.

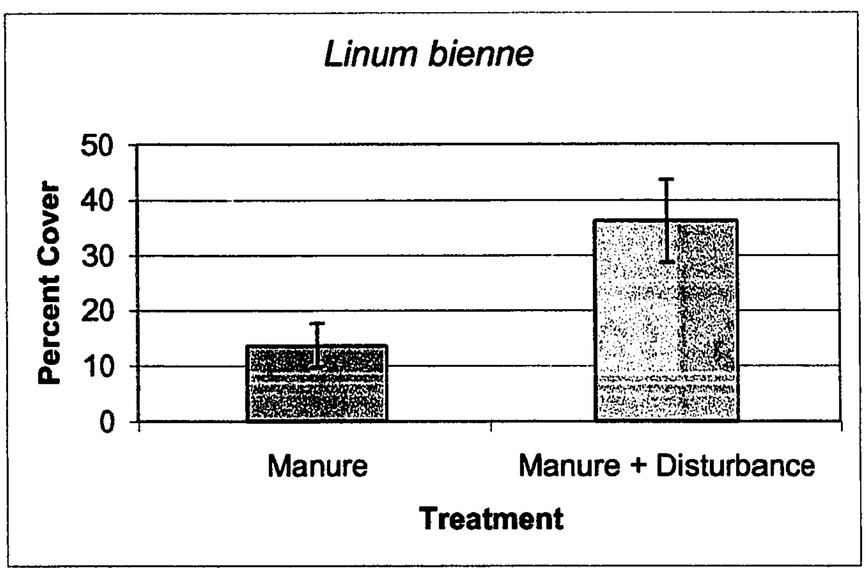

Figure 34. Percent cover of *Centaurea solstitialis* (yellow star thistle). One-way ANOVA post hoc comparisons of the means (paired contrasts) showed that cover in hiking was significantly higher than horse plots ($p = 0.035$) and tended to be higher than control plots ($p = 0.074$). N = 6. Error bars represent standard error around the mean.

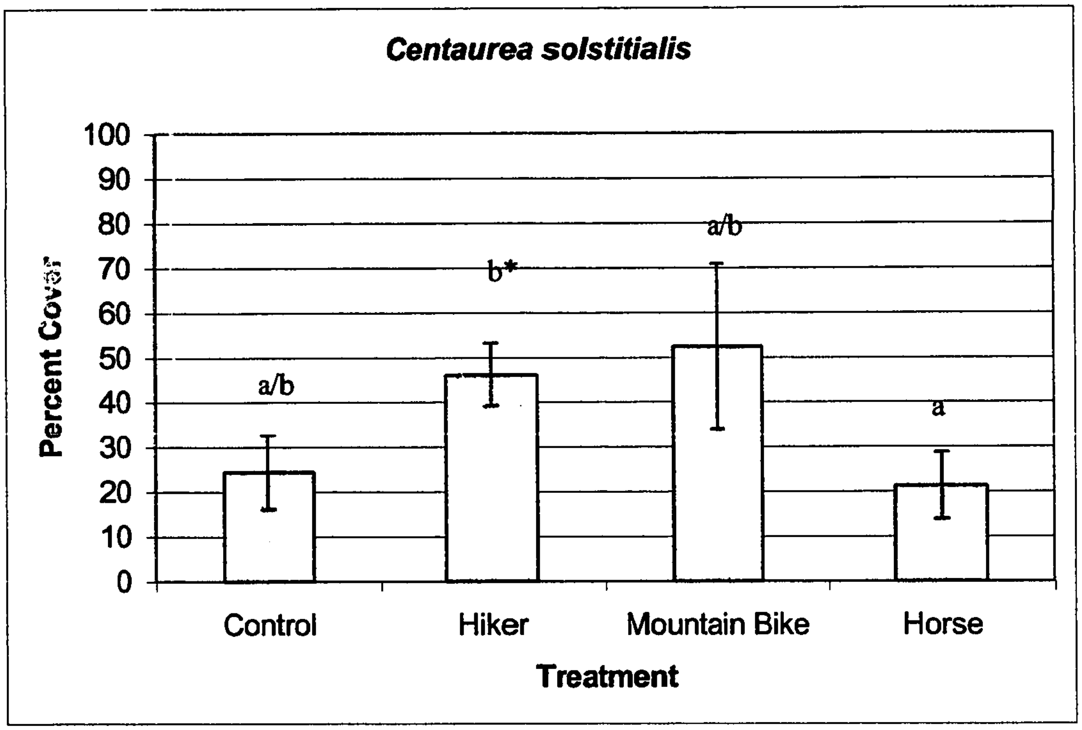

Figure 35. Mean total percent cover of non-native species for each treatment type. Includes *Centaurea solstitialis* (yellow star thistle), *Erodium botrys* (broadleaf filaree), *Geranium dissectum* (cutleaf geranium), *Plantago lanceolata* (English plantain), *Vicia sativa sativa* and *V. sativa nigra* (spring vetch and narrowleaf vetch), *Sherardia arvensis* (field madder) *Medicago lupulina* (black medick), *Anagallis arvensis* (scarlet pimpernel) *Linum bienne* (narrowleaf flax) and *Rumex acetosella* (sheep-sorrel). One-way ANOVA and post-hoc comparisons of means (paired contrasts) revealed that exotic cover in mountain biking plots tended to be higher than that of control plots (p = 0.069). N = 6. Error bars represent standard error around the mean.

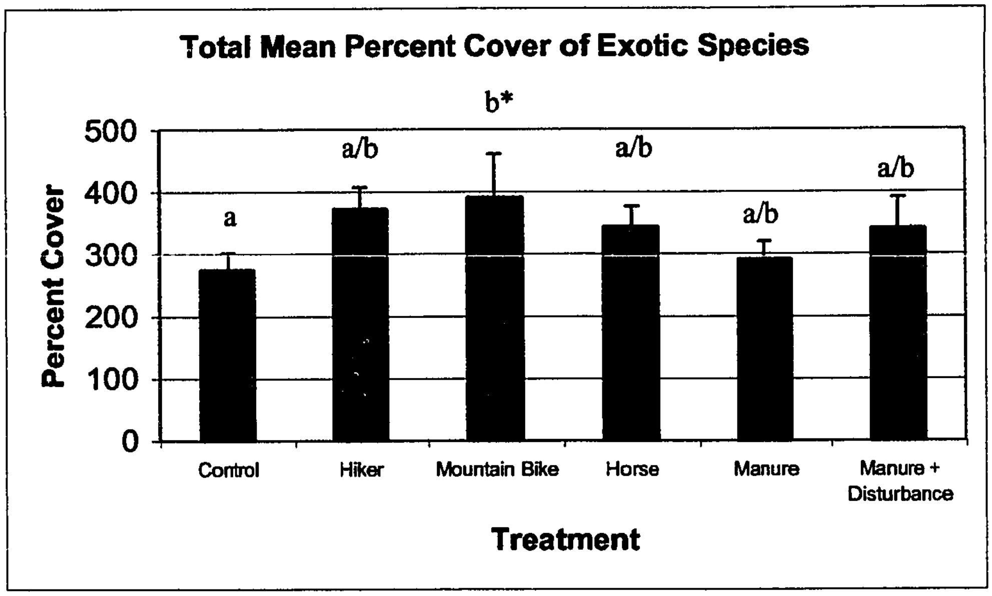

Figure 36. Percent cover of *Sherardia arvensis* (field madder). Cover in plots trampled by a hiker was significantly higher than control plots (p = 0.034). N = 6. Error bars represent standard error around the mean.

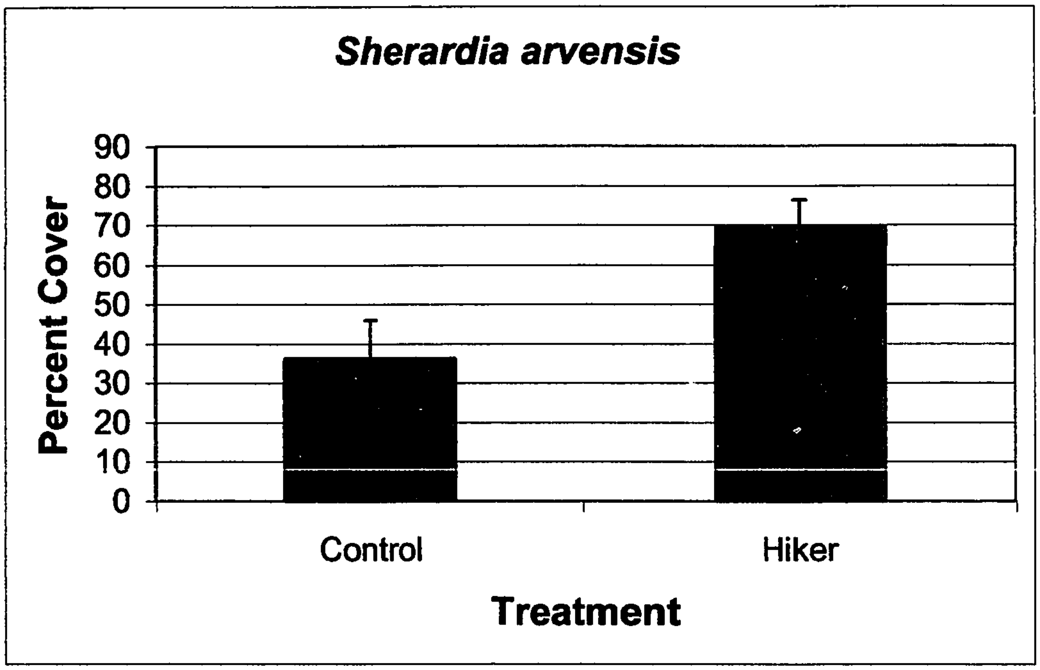

Figure 37. Total mean cover for all native plants per quadrat in the experimental study. Includes *Sisyrinchium bellum* (blue-eyed grass), *Madia sativa* and *M. gracilis* (Coast tar weed and Slender madia), *Lotus* species, *Lupinus* species (lupine), *Sanicula* species, *Juncus* species (rush), *Calystegia* species (morning glory), and *Wyethis* species (Mule-ear). One-way ANOVA and post-hoc pair-wise contrasts revealed a significant difference between native cover in control and horse plots ($p = 0.040$). Significant results are marked with an asterisk. N = 6. Error bars indicate standard error around the mean.

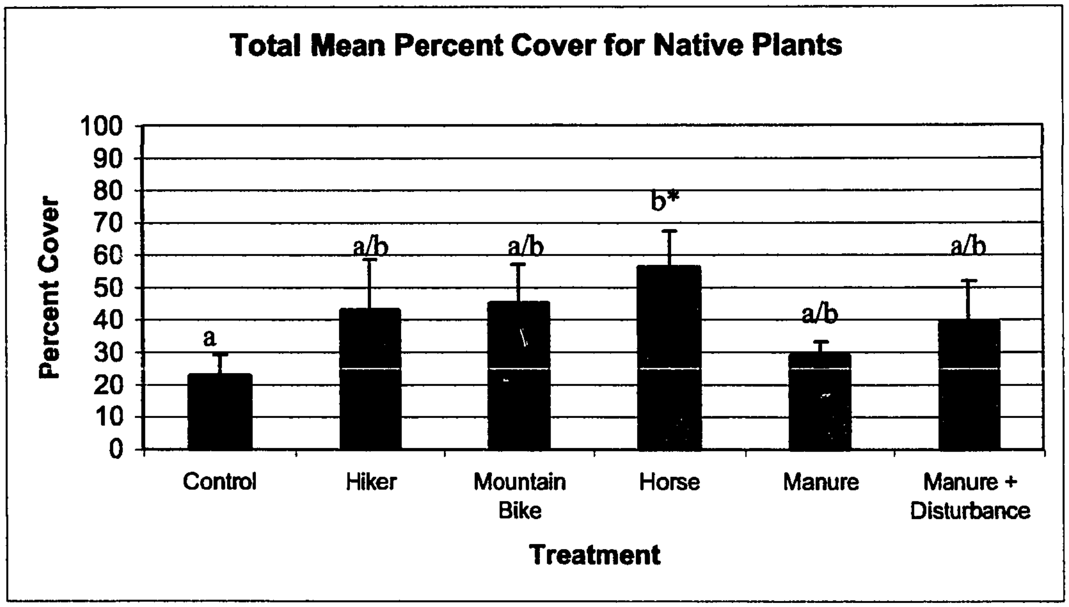

Figure 38. Combined percent cover of *Madia sativa* (coast madia) and *Madia gracilis* (slender madia). Cover in plots trampled by a horse was significantly higher than control plots ($p = 0.037$). N = 6. Error bars represent standard error around the mean.

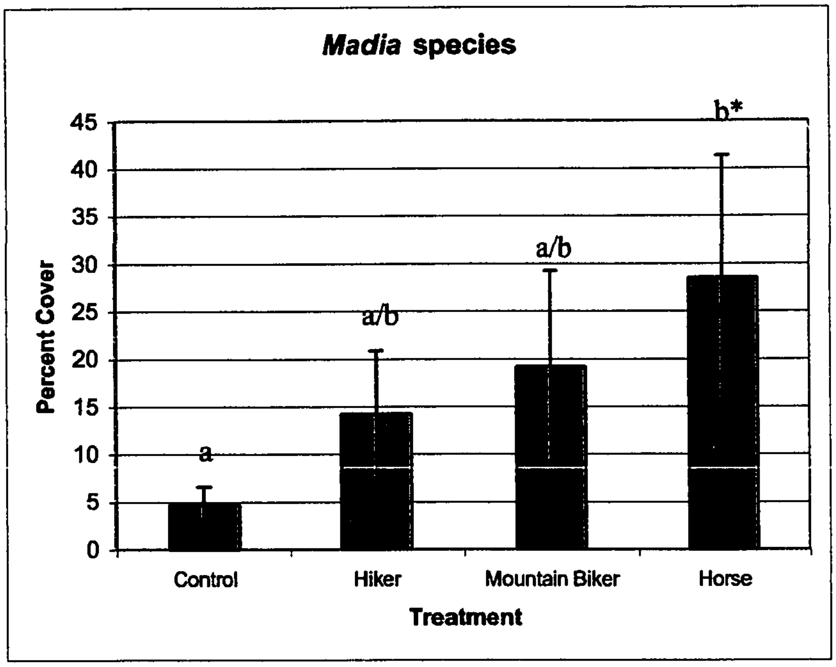

Figure 39. Shannon-Weiner diversity index (H') values for non-native species. One-way ANOVA post hoc comparisons of means suggested that hiker plots were significantly more diverse than horse plots (p = 0.025).